



LNG as a ship fuel in Iceland

A feasibility study

Guðrún Jóna Jónsdóttir

Thesis of 30 ECTS credits

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Abstract

Stricter regulations on emissions from ships within Emission Control Areas (ECA) set by the International Maritime Organization has led to increased number of ship owners around the world switching to liquefied natural gas (LNG) as a fuel. LNG is a cleaner burning and less expensive fuel than conventional oil.

This thesis focuses on the benefits and disadvantages of using LNG as a ship fuel. The Icelandic fishing fleet was analyzed to evaluate if the fleet would gain from switching to LNG as a fuel. A study was conducted to assess the economic and environmental feasibility for the Icelandic ship owners to switch from Marine gas oil (MGO) to dual-fuel LNG propulsion where LNG would be used as the main fuel and MGO as a back-up fuel. Current operational cost of wetfish trawlers and pelagic vessels was compared to the estimated operational cost if the ships would switch to dual-fuel LNG propulsion to assess if the operational savings gained would pay up the investment cost needed over an acceptable time. The investment options were to convert existing ships or add to the investment cost of new ships with dual-fuel LNG propulsion. The emissions of four pollutants from the ships before and after a switch was also compared.

The results of the study showed that the environmental gain would be significant.

The results for the economic feasibility were dependent on the ships installed power and oil consumption as well as the different fuel price scenarios used in the study. Increased oil consumption of ships strengthens the feasibility of switching to LNG as a fuel as well as if MGO prices continue to rise in the future.

The pelagic vessels showed better feasibility than the wetfish trawlers due to lower proportion of MGO required after a switch to dual-fuel LNG propulsion and higher fuel consumption.

As oil prices are predicted to increase in the future, LNG as a ship fuel for the Icelandic fishing fleet could be a viable option.

Keywords: Ship fuel; LNG; fishing fleet; Iceland; emission reduction

Ágrip

Vegna hertra reglugerða varðandi útblásturs mengun skipa innan Mengunareftirlitssvæða (ECA) sett af Alþjóðasiglingarmálastofnuninni (IMO) hafa margir skipaeigendur í heiminum verið að skipta yfir í fljótandi jarðgas (LNG) sem eldsneyti fyrir skip sín. LNG hefur hreinni bruna og lægra verð en hefðbundin olía.

Þessi ritgerð einblínir á kosti og galla þess að nota LNG sem eldsneyti fyrir skip. Íslenski fiskiskipaflotinn var rannsakaður til að meta hvort hann myndi hagnast af því að skipta yfir í LNG sem eldsneyti. Rannsókn var framkvæmd til að meta efnahags- og umhverfislega hagkvæmni þess fyrir íslenska skipaeigendur að skipta yfir í tvískipt orkukerfi þar sem LNG er notað sem aðal eldsneyti og skipagasolía (MGO) sem vara eldsneyti. Núverandi rekstrarkostnaður fyrir ísfiskiskip og uppsjávarskip var borin saman við áætlaðan rekstrarkostnað ef skipin myndu skipta yfir í tvískipt orkukerfi til að meta hvort að fengin rekstrarsparnaður myndi borga upp þá fjárfestingu sem þyrfti á ásættanlegum tíma. Fjárfestingarkostirnir eru annað hvort að breyta núverandi skipum eða bæta við fjárfestingarkostnað nýrra skipa þannig að þau væru með tvískipt orkukerfi. Útblástursmengun skipanna á skipagasolíu sem eldsneyti var borin saman við áætlaða útblástursmengun ef skipin myndu skipta yfir í tvískipt orkukerfi.

Niðurstöður rannsóknarinnar sýndu töluverðan umhverfislegan ábata við það að skipta yfir í tvískipt orkukerfi. Niðurstöður fyrir efnahagslegt hagkvæmni voru háðar vélarafli skipanna, olíu notkun og mismunandi verð eldsneytis sem notað var í rannsókninni. Aukin olíu notkun skipa styrkir þann kost að skipta yfir í LNG sem eldsneyti og einnig ef verð á skipagasolíu mun halda áfram að hækka í framtíðinni.

Uppsjávarskipin sýndu meiri hagkvæmni heldur en ísfiskiskipin vegna lægra hlutfalls af skipagasolíu sem þyrfti ef skipt yrði yfir í tvískipt orkukerfi og vegna meiri eldsneytisneyslu. Þar sem spáð er fyrir því að olíuverð muni hækka í framtíðinni, gæti LNG sem eldsneyti fyrir skip verið hagkvæmur kostur fyrir Íslenska fiskiskipaflotann.

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In this thesis a comma is used for a decimal mark and a dot as a thousand separator for all numbers.

Abbreviations

BOG - Boil off gas

C3/MR - The propane pre-cooled mixed refrigerant

CNG - Compressed natural gas

CO₂ - Carbon dioxide

DMA - Dansk Maritime Authority

DMR - Double mixed refrigerant

DNV - Det Norske Veritas

DR - Discount Rate

EBITDA - Earnings before interest, taxes, depreciation and amortization.

EIA - Energy Information Administration

EUR - Euros

GDP - Gross domestic product

GHG - Greenhouse gas

GT - Gross tonnage

HFO - Heavy fuel oil

IMO - International Maritime Organization

IRR - Internal rate of return

ISK - Icelandic Króna, the national currency of Iceland

ISO - International Organization for Standardization

LFL - Lower flammability level

LHV - Lower heating value

LNG - Liquefied natural gas

MARPOL - International Convention for the Prevention of Pollution From Ships

MGO -Marine gas oil

NO_x - Nitrogen oxide

NPV - Net present value

OECD - Organization for Economic Co-operation and Development

PBP - Payback period

PM - Particulate matter

PS - Price scenario

R/P-ratio - Reserves to production ratio

RoRo - Roll on Roll off

RPT - Rapid Phase Transition

SIGTTO - Society of International Gas Tanker and Terminal Operators

SO_x - Sulphur Oxide

UFL - Upper flammability level

US - United States

WCR - Waste cold recovery

ECA - Emission Control Areas. Existing areas are the Baltic Sea, North Sea and the California coast.

IGC code - The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).

IGF code - The International Code of Safety for Gas-Fuelled Ships

DMA-report - North European LNG Infrastructure Project: A feasibility study for an LNG filling station infrastructure and test of recommendations.

Dual-fuel LNG propulsion - Ships running on LNG (in gas mode) as a main fuel using MGO (in diesel mode) as a back-up fuel.

Units

Wh - Watt hour

kWh - kilo Watt hour (1.000 Watt hours) 1kWh = 3,6 MJ

MJ - Mega Joule, 1.000.000 Joule = 1MJ = 0,28 kWh

MBTU - Million British Thermal Unit, 1 MBTU = 293 kWh = 1.055 MJ

kW - kilo Watt, 1.000 Watt, 1 kW=1,34 hp =3,6 MJ/h

m³- Cubic meter = 1.000 liters

Tonne = 1.000 kg

MT - Mega tonne = 1.000.000 tonnes

Gg - Gigagram = 1.000.000.000 grams

LNG energy = 13,5 kWh/kg = 48,6 MJ/kg

LNG density = 440 kg/m³ = 0,440 kg/l

MGO energy = 11,9 kWh/kg = 42,6 MJ/kg

MGO density = 836 kg/m³ = 0,836 kg/l

1. Introduction

Global warming is a worldwide problem and many environmental policies and regulations have been adopted with the goal to reduce greenhouse gas (GHG) emission. Economic instruments such as carbon tax has been implemented in some countries where a fee is levied on fossil fuels to encourage reduction in consumption or a switch to alternative fuels [1]. Global warming is affecting fisheries where the rise in oceans temperature and increased acidification is having a negative effect on the marine ecosystem [2:5]. Responding to global warming by reducing emissions of harmful pollutants from fisheries should therefore be a high priority.

The International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI sets limits on sulphur oxides (SO_x) and nitrogen oxides (NO_x) emission from ships. As of 2015 and 2016 stringent limitations will be set on SO_x and NO_x emission within the Emission Control Areas (ECA) [3:7]. To comply with these requirements within the ECA the ship owners especially in Europe have been switching to alternative fuel such as Liquefied natural gas (LNG) [4:1].

LNG is natural gas that has been cooled down to approximately -161.5°C (-260°F) at close to atmospheric pressure converting it to liquid [5]. LNG is a cleaner burning and less expensive fuel than conventional oil [6:3]. A ship running on LNG instead of oil eliminates SO_x emission and NO_x is reduced by 85-90%. Particulate matter (PM) emission is reduced by 90% and carbon dioxide (CO₂) by 20-25% [3:3]. This shows that using LNG as a ship fuel would greatly reduce harmful emissions from ships.

LNG has been used as a ship fuel for many years now where it has proven its safety and technical feasibility in many ship types [3:12]. However it has currently not been applied to fishing ships but they are also suitable for running on LNG as a fuel [7:4].

The Icelandic economy relies heavily on the fishing industry that accounts for a large share of the country's export earnings [8:5]. The fishing fleet is energy demanding and consumes large amount of oil each year resulting in high emissions of harmful pollutants [9:17]. The Marine gas oil (MGO) prices in Iceland have been rising over the past years with the world's market price increasing and in addition a carbon tax has been imposed on all fossil fuels [10],[11:22]. This shows that the Icelandic fishing fleet could benefit from a cheaper more environmentally friendly fuel to lower the operational cost as well as to reduce emissions.

The aim of the thesis was to assess the economic and environmental feasibility for the Icelandic fishing ship owners to switch to LNG as a fuel. The main research questions addressed were:

- 1) What are the benefits and disadvantages of switching to LNG as a ship fuel?
- 2) What are the main drivers and obstacles to a switch?
- 3) Would the Icelandic fishing fleet benefit from a switch?
- 4) Would it be feasible for the Icelandic fishing ship owners to switch to LNG propulsion?

The main benefits and disadvantages of using LNG as a ship fuel were identified as well as the main drivers and obstacles. The Icelandic fishing fleet was analyzed to evaluate if the fleet would benefit from switching to LNG as a fuel. A feasibility study was conducted where three wetfish trawlers and three pelagic vessels from a fishing company in Iceland were selected and the ships operational cost last year was compared to the estimated annual operational cost if the ships would switch to dual-fuel LNG propulsion to assess if the operational savings gained would pay up the investment cost needed over an acceptable time. The investment options were to convert existing ships or add to the investment cost of new ships with dual-fuel LNG propulsion. The emissions of four pollutants from the ships running only on MGO and after a switch to dual-fuel LNG propulsion was also compared.

The results of the study showed that the environmental gain would be significant, especially in reducing SO_x and NO_x emission. The results also indicate that increased MGO consumption of ships strengthens the advantage of switching to LNG as a fuel.

The results for the feasibility were dependent on the ships installed power and oil consumption as well as the different fuel price scenarios used in the study. Increased oil consumption of ships strengthens the feasibility of switching to LNG as a fuel as well as if MGO prices continues to rise in the future. The pelagic vessels showed better feasibility than the wetfish trawlers due to lower proportion of MGO required after a switch to dual-fuel LNG propulsion and higher fuel consumption. As oil prices are predicted to increase in the future, LNG as a ship fuel for the Icelandic fishing fleet could be a viable option.

The thesis is structured as follows:

Chapter two contains the literature review where the theoretical background of the use of LNG as a fuel for ships is outlined.

Chapter three goes over the methodology of the thesis, how the subject was approached. How information and data was collected and analyzed and how the feasibility study was conducted.

In chapter four LNG is explained, how it is formed, its main ingredients, its density and energy content compared to oil.

Chapter five accounts for the amount of proven natural gas reserves, the growth past years and how long these reserves are expected to last compared to oil. The amount and distribution of the world's LNG imports and exports is outlined.

The LNG value chain is described in chapter six. The whole process is explained from the extraction of natural gas from the ground to the delivery of LNG to end users such as the ship owners.

Chapter seven explains the use of LNG as a ship fuel, what regulatory frameworks regarding the use of LNG as a fuel exist today, the engine options available and the tank types used. The main safety issues regarding the use of LNG is assessed. The supply of LNG in Europe is presented, with the bunkering possibilities and the existing, planned and proposed LNG terminals. The main benefits and disadvantages with using LNG as a ship fuel are evaluated and the main drivers and obstacles identified.

Chapter eight describes the Icelandic fishing fleet. The existing number of ships and the trend past years, average age of the fleet and its annual oil consumption. The oil price to the ship owners in Iceland and its development past years is presented and the imposed carbon tax explained. The annual GHG and CO₂ emission from the fishing industry is accounted for.

Chapter nine contains the feasibility study. The cost of MGO and LNG in Iceland was assessed. The LNG and MGO demand for the ships after a switch to dual-fuel LNG propulsion was calculated from the ships MGO consumption last year. The operational cost before and after a switch was compared. The investment cost of a conversion and the added investment cost of a new ship were estimated. A Net Present Value (NPV) calculation was conducted to assess if the annual operational savings gained would pay up the two investment options over an acceptable time. The environmental feasibility was assessed by comparing the emission of four pollutants for the ships running only on MGO and the emission reduction gained by switching to dual-fuel LNG propulsion.

Chapter ten summarizes the main results of the feasibility study. The economic results from the NPV calculations and the environmental reduction achieved for each ship. The total emission reduction from all ships combined was evaluated.

In chapter eleven the main results of the study are discussed and evaluated with regard to the aim of the thesis and the research questions raised.

Chapter twelve contains the final conclusion of the feasibility study.

2. Review of literature

The possibility of using LNG as a ship fuel is a widely researched topic with many published papers. This thesis is mainly built on the source "*North European LNG Infrastructure Project: a feasibility study for an LNG filling station infrastructure and test of recommendations*" issued by the Danish Maritime Authority (DMA) and co-financed by the European Union. The background for the study was the development of a green transport mode of shipping. Stricter regulations from the International Maritime Organization (IMO) on emissions from ships within Emission Control Areas (ECA) pushes for new technologies for ships like switching to LNG as a fuel as it is more environmental and climate friendly than conventional oil. An infrastructure for LNG is limited and LNG storage and distribution system has to be established. The study focused on this problem and provided recommendations covering the LNG supply chain from LNG import terminals to ships using LNG as a fuel. The aim was to provide central stakeholders with recommendations to create a cost efficient infrastructure for LNG.

A report released by Det Norske Veritas (DNV) in 2011 "*Greener shipping in North America*" concludes that environmentally and economically LNG as a ship fuel is the best solution from the three options ship owners within the ECA are faced with: switching to fuel with low sulphur content (MGO), use heavy fuel oil (HFO) and remove the sulphur from the exhaust gas by installing scrubbers or switching to alternative fuel such as LNG. The study covers the North American shipping statistics, the emission legislations, the economic and environmental performance of LNG as well as LNG's technology, safety and availability. The study claims that LNG can be made available in North America and will expand as more ship owners switch to LNG.

These two reports above mainly address the possibility of using LNG as a fuel for large ships, such as RoRo vessels, Costal/bulk/chemical tankers and Container vessels. There are currently no LNG fuelled fishing ships in operation, but some fishing articles in Norway claim that fishing owners are looking in to this possibility. The DNV innovation project "*Fish 2015*" introduces the designs of the first LNG fishing ship of the future "Catchy" for fishing with pelagic trawling and purse seine. It provides flexible operation, energy efficiency and improved and safer working conditions. It shows that LNG can be used as a fuel for fishing ships.

The paper "*Emission Reduction in the Norwegian Fishing Fleet: Towards LNG?*" (Jafarzadeh, Ellingsen and Utne, 2012) addresses the main challenges and benefits with implementing LNG as a fuel in the Norwegian fishing fleet to reduce emission. The fishing fleet was analyzed and the result showed that the Norwegian trawlers are the most energy demanding ships of the fishing fleet and emit most of pollutants. A calculation was made to assess the emission reduction gained from a switch to LNG propulsion for a trawler. The conclusion stated that the Norwegian coastal trawlers are best suited to switch to LNG due to limited bunkering facilities in Norway and the high investment needed for LNG ships.

The report "*Life cycle assessment of marine fuels*" is a comparative study of four fossil fuels for marine propulsion (Bengtson, Anderson and Fridell, 2011). The aim of the report was to investigate the environmental performance of marine fuels that can be used within ECA after more stringent requirements of SO_x emission are implemented in the year 2015 and of NO_x emission in the year 2016. The fuels are four fossil fuels combined with two exhaust gas cleaning techniques. The results of the study showed that LNG can have somewhat lower global warming potential than the other fuels and the acidification and eutrophication contribution are much lower.

There are currently no papers published about the possibility of implementing LNG as a fuel for the Icelandic fishing fleet. This thesis can therefore contribute to existing research on the possibility of using LNG as a fuel for fishing ships and be important to assess if LNG could become the future ship fuel in Iceland.

3. Methods

The method used for this report was mainly desk based analysis of collected data and literature regarding the subject. First chapters of the thesis were derived from other sources such as reports, papers, articles, books and the internet . The purpose is to explain LNG and how it can be used as a fuel for ships. The Icelandic fishing fleet was analyzed using mainly information obtained from the internet and data collected from Statistics Iceland. The aim was to assess how a switch to LNG as a fuel could benefit the fleet. A feasibility study was conducted to assess if it would be feasible for ship owners in Iceland to switch to LNG as a fuel. In this chapter the feasibility study will be explained.

First the end-user price of MGO and LNG to the ship owners in Iceland had to be established. A fuel company in Iceland was contacted for information about the average MGO price per tonne last year. For the study it was decided to use two price levels of "Central" and "High" for MGO as is done in the DMA-report *"North European LNG Infrastructure Project"* [12:68]. The "Central" MGO price used in the study was the average price of MGO in Iceland last year (2012) and for the "High" price an estimated 20% margin was added on the "Central" price. The estimated price of LNG in Iceland was based on prices from the DMA-report where "Low", "Central" and "High" price levels were used. The import LNG prices were obtained from the DMA-report but instead of adding 170 €/tonne for infrastructure cost an estimated 11,5% margin was added on the infrastructure cost making it 190 €/tonne. This was done to correct for longer distances in transshipment of LNG to Iceland as well as the likelihood of higher investment cost for infrastructure. In addition a carbon tax was added on the end-user price. For this study it was assumed that an infrastructure for LNG exists in Iceland and the local ship owners could buy LNG at the estimated prices.

Next cooperation was sought with the one of the largest fishing company in Iceland HB Grandi. From their fleet six ships were selected for the study, three wetfish trawlers and three pelagic vessels. Information about each ship was gathered from HB Grandi. General information about the ships: Name, type, age, size, fuel tank size, engine type, power and auxiliary power. In addition information about the ships MGO consumption last year (2012) as well as number of days out at sea and average length of voyages was received.

It was decided that the ships would switch to dual-fuel LNG propulsion where LNG would be used as the main fuel and MGO as a back-up fuel. From past year oil consumption, future

LNG and MGO demand were calculated for each ship. It was decided to add a 20% margin to the average length of voyage for each ship to ensure sufficient energy supply.

After a switch to dual-fuel LNG propulsion some MGO would still be needed when the ship is operating at high engine loads (over 80% of the installed power) as well as at low engine loads (below 15% installed power) [13:12] and a small amount is needed to ignite the LNG for combustion [14:21]. Information was received from HB Grandi that it was estimated that the wetfish trawlers would operate at high engine loads for about 25% of the voyage and the pelagic vessels for about 10% of the voyage, see Appendix 10.1. The ships are almost never operating at engine loads below 15%, just when the engine is turned on and off and then the MGO consumption is very small, see Appendix 10.2. It was therefore decided to exclude it from the study.

From the average length of a voyage (in hours) for each ship the estimated time at high engine load period (25% or 10%) was calculated. It was assumed that during high engine load periods the ships would use on average 90% of the total installed power. From the power needed at high engine loads and the number of hours during this period the total output energy (kWh) needed at high engine loads for each ship was calculated. With a 45% efficiency of the diesel engine [15:6] the total input energy in kWh was calculated. With one kg of MGO containing 11,9 kWh [16] the amount of MGO (in kg) needed at high engine loads for each ship was established. The amount was then converted to liters by dividing with the MGO density of 0,836 kg/L [14:7].

The MGO needed at high engine loads after a switch to dual-fuel LNG propulsion was then subtracted from the total MGO the ship consumed last year. From the remaining MGO one percent was needed as ignition source for the LNG and the rest of the MGO was converted to LNG by multiplying with a factor of 1,6 to get the same amount of energy in liters [17:5]. From that the volume of the LNG tank required for each ship could be assessed, but one cubic meter contains one thousand liters and the filling ratio of the LNG tanks is 90% [18:3]. From these calculations the amount of MGO and LNG needed per voyage after a switch to dual-fuel LNG propulsion was multiplied with the number of voyages per year to get the total amount of MGO and LNG required per year.

The engine manufacturing company Wärtsilä was contacted for cost estimations of converting similar ships as in the study to run on dual-fuel LNG propulsion. For estimations on the added investment cost imposed on new ships by installing a dual-fuel LNG system, a graph from

DNV was used where the added cost (€/kW) was estimated from the total installed power of the ships [19:11].

The operational cost before and after was compared to see if some operational savings would be gained by switching the ships to run on dual-fuel LNG propulsion. The total maintenance cost last year for each ship was received from HB Grandi. It was assumed that the maintenance cost after a switch to dual-fuel LNG propulsion would be 5% more. The total fuel cost per year for each ship (before and after) was calculated from the last year MGO consumption and from the estimated MGO and LNG demand by switching to dual-fuel LNG propulsion and the estimated fuel cost of MGO and LNG. From the estimated fuel costs of MGO and LNG, six price scenarios were used as an example from the DMA-report [12:68]. From these six price scenarios the total annual fuel savings for each ship after a switch to dual-fuel LNG propulsion was calculated. Then the added cost for maintenance was subtracted from the fuel savings giving the total annual operational savings of each ship.

From the investment cost of the two investment options and the total operational savings gained each year for the ships the economic feasibility was calculated using the Net Present Value (NPV) method with a 10% discount rate over an economic lifetime of 20 years.

To assess the environmental feasibility the emissions of four pollutants (SO_x, NO_x, PM and CO₂) from the ships running only on MGO was compared to the emissions after a switch to dual-fuel LNG propulsion. The emission difference (g/kWh) for MGO and LNG of the four pollutants was received from an emission comparison table [20:2].

The feasibility study is in chapter nine where calculations of one wetfish trawler are explained in more detail.

4. What is LNG?

Liquefied natural gas (LNG) is natural gas that has been converted into liquid state. The liquefaction process involves removing some components, such as dust, helium, acid gases, water and heavy hydrocarbons. The natural gas is then cooled down to approximately -161.5°C (-260°F) at close to atmospheric pressure converting it to liquid. By doing so the volume is reduced about 600 times than in its gaseous form making it easier for storage and shipment in special cryogenic sea vessels to receiving terminals all over the world [21].

Natural gas is a fossil fuel where the main ingredient is methane (CH_4), a gas which is composed of one carbon atom and four hydrogen atoms. Natural gas is formed from the decaying remains of pre-historic plants and animals. These decaying remains are organic material and when exposed to heat and pressure over thousands of years some changes into coal, oil and natural gas. Unlike coal and oil, natural gas is clean burning and emits lower levels of harmful chemicals into the air. Natural gas is colorless, shapeless, and odorless in its pure form but a odorant called mercaptan that smells like "rotten eggs" is added to the gas before it is delivered to users for safety reasons to detect any harmful leaks [5].

Though natural gas consists mainly of methane, it can also include ethane, propane, butane and pentane. The combination of these chemicals in natural gas can vary depending on the source. Table I shows a typical combination of natural gas before it is refined [5].

TABLE I.
COMBINATION OF CHEMICALS IN NATURAL GAS

Chemical	Formula	Percentage
Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne, Xe	trace

As a result of removing certain components from the natural gas during the liquefaction process, the LNG consist about 95% of methane and 5% other chemicals [22:17]. The main physical and chemical properties of LNG is found in Table II.

TABLE II.
PHYSICAL AND CHEMICAL PROPERTIES OF LNG [23:15]

Properties	LNG
Auto ignition point (°C)	540
Flash point (°C)	-187
Boiling point (°C)	-160
Flammable range (%)	5-15
Stored pressure	Atmospheric
Toxic	No
Carcinogenic	No
Health hazards	None

LNG's density is between 430 kg/m³ and 470 kg/m³, depending on its temperature, pressure and composition [24:3]. The energy content based on the lower heating value (LHV) of LNG is about 48,6 MJ/kg which is higher than the energy content of MGO with a LHV of 42,6 MJ/kg [16]. But the energy density of one liter of LNG is about 21,4 MJ¹ and that is only 60% of the energy density of MGO which is 35,6 MJ/L².

5. Natural gas reserves

Over the past 20 years the reported level of global natural gas reserves have grown by 50%, exceeding the growth in global oil reserves over this same period. Since the year 1980 the world's natural gas reserves have increased by 3,1% on average every year, see Figure 1 [25:64].

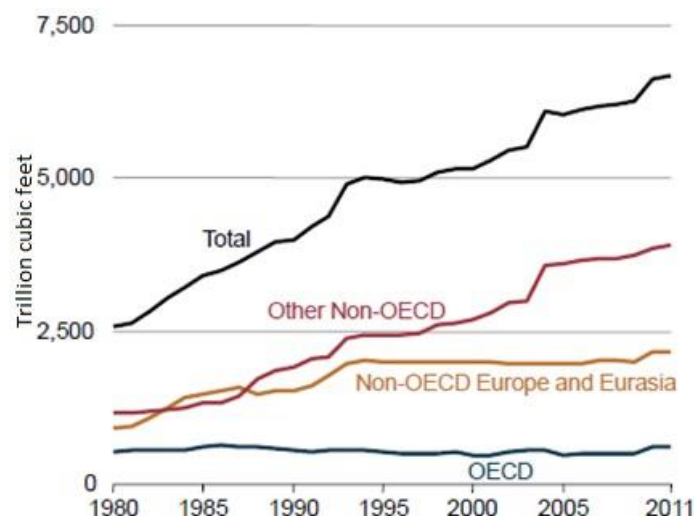


Figure 1. World's natural gas reserves growth by region [25:64]

¹ Density of LNG (at -162° C) = 440 kg/m³ = 0,44 kg/l [14:19]; Energy density of LNG = 48,6 MJ/kg * 0,44 kg/L = 21,4 MJ/L.

² Density of MGO (at 15° C) = 836 kg/m³ = 0,836 kg/l [14:19]; Energy density of MGO = 42,6 MJ/kg * 0,836 kg/L = 35,6 MJ/L.

Natural gas reserves have mainly grown in non-OECD Europe and Eurasia, the Middle East, and the Asia-Pacific region. As of January 1, 2011, the world's proven natural gas reserves were estimated to be 6.675 trillion cubic feet (189 trillion cubic meters) [25:64]. Figure 2 shows how these reserves are distributed around the world.

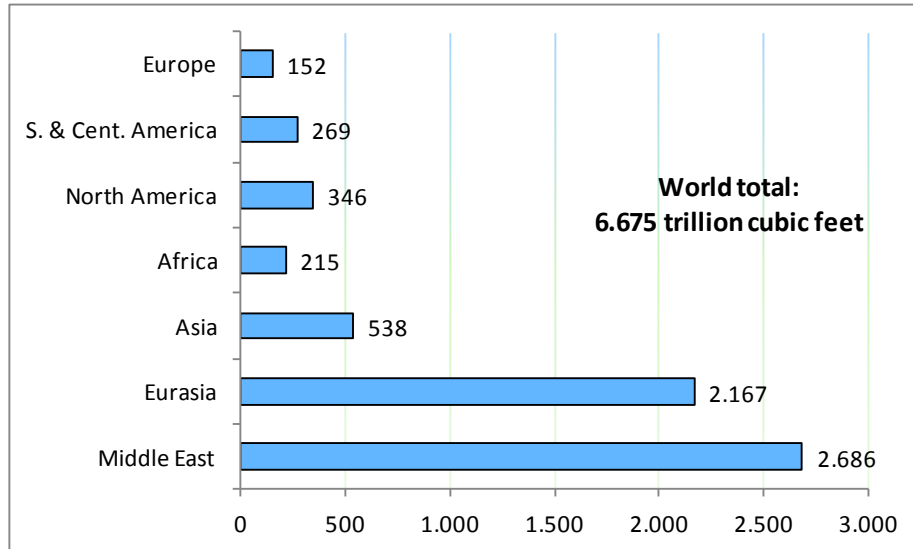


Figure 2. World's natural gas reserves by geographic region, 2011 [25:64]

Most of the world's natural gas reserves or about three-quarters are in the Middle East and Eurasia, the rest are distributed fairly equally between the other regions.

In addition to the world's proven natural gas reserves the estimated amount of technically recoverable shale gas resources in 32 countries are about 6.622 trillion cubic feet [25:3]. Shale gas is called "unconventional gas" because it is not recovered as conventional gas, a special process is required. The main technologies used are horizontal drilling and hydraulic fracturing (fracking). By injecting water, sand and chemicals into a horizontal borehole at a high pressure, the shale rocks are fractured releasing the gas [26:2], see Figure 3.

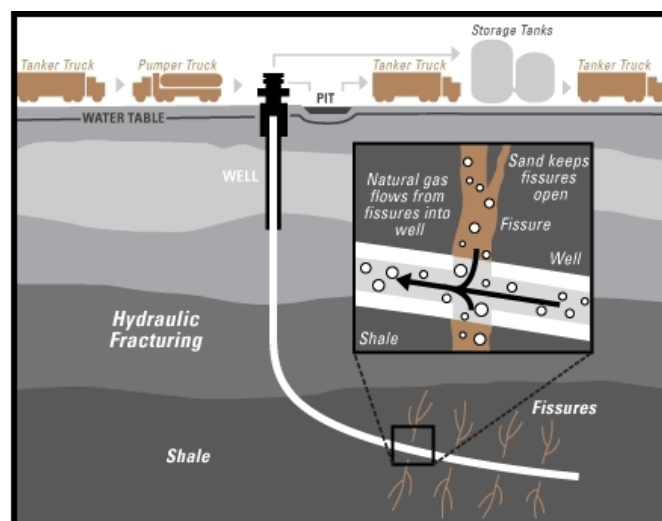


Figure 3. Hydraulic Fracturing of shale gas [27]

Shale gas has gained importance as a natural gas source worldwide, especially in the United States (US). Of the domestic gas production in the US in the year 2000 less than 1% came from shale gas. In the year 2010 it had risen to 20% and the Energy Information Administration (EIA) predicts that in the year 2035 shale gas will account for 46% of the US gas supply [26:2]. Some concern has risen over the potential environmental impacts of hydraulic fracturing such as ground water contamination and gas leaks contributing to greenhouse gas (GHG) emission resulting in a ban or suspension in some countries [26:6]. Studies in assessing these environmental concerns are in progress [25:53].

The world's energy supply of natural gas are expected to expand greatly with potential shale gas reserves. It is estimated that China has the largest shale gas reserves in the world [28:4].

5.1 Export of LNG

Most of the world's LNG supply comes from countries that hold large natural gas reserves. These countries are Algeria, Australia, Brunei, Indonesia, Libya, Malaysia, Nigeria, Oman, Qatar, Trinidad and Tobago [29].

At the end of 2011, eighteen countries were exporting natural gas as LNG. Five other countries, Belgium, Brazil, Mexico, Spain and the United States were re-exporting LNG imported from another source. The total world's LNG exports in the year 2011 was 241,5 MT and Figure 4 shows how the LNG exports were distributed by the exporting countries [30:7].

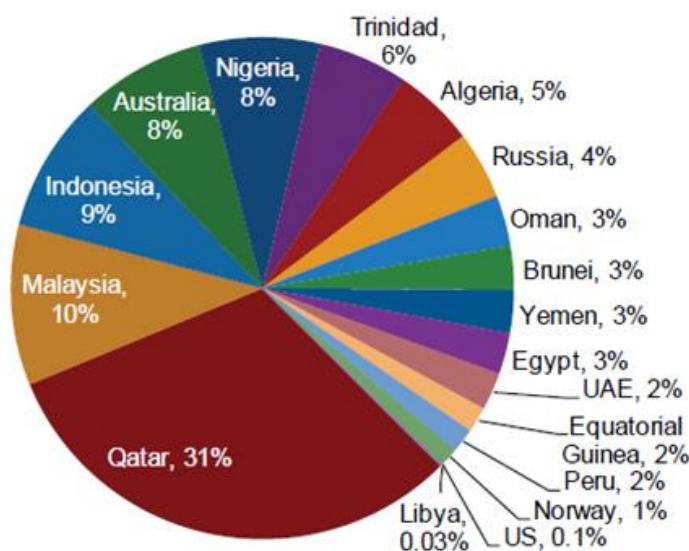


Figure 4. LNG Exports by Country, 2011 [30:8]

Qatar is the largest LNG exporter in the world, supplying 75.5 MT of LNG to the market in 2011 and was that about one third (31%) of the world's LNG supply [30:7].

5.2 Import of LNG

The world's dominant LNG importers are Japan and Korea with a 48% consumption of the total LNG supply to the market in 2011. Because of the Fukushima nuclear disaster the demand for LNG in Japan has increased due to the increased gas-fired power replacing the country's nuclear power. Many small LNG importers have been emerging over the past years increasing the global LNG imports. The total LNG imports in the year 2011 was 241,5 MT and Figure 5 displays how the world's imports were distributed [30:10].

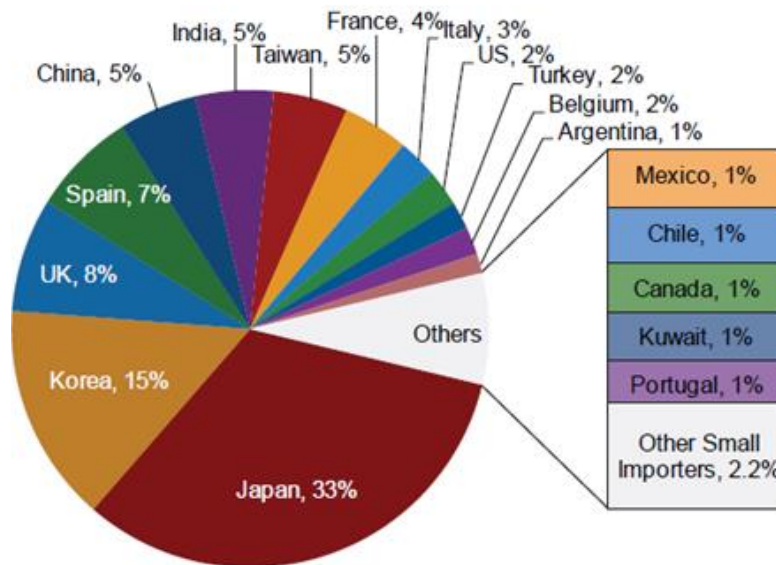


Figure 5. LNG Imports by Country, 2011 [30:11]

Most of the world's LNG is consumed in the Asia-Pacific region, about 153 MT or 63% of the world's LNG import in the year 2011. Most of the supply comes from within the region but the Middle East provides 54% of the regions supply and North Africa provides 37% [30:15].

5.3 Reserves-to-production ratio of natural gas

Even though there has been an increase in natural gas consumption, especially over the past decade most regional reserves-to-production (R/P) ratios³ have still remained high [31:20]. Figure 6 shows the estimated R/P ratio per region in the year 2011.

³ The remaining amount of a proven resource expressed in years. R/P = Known resource/amount used per year.

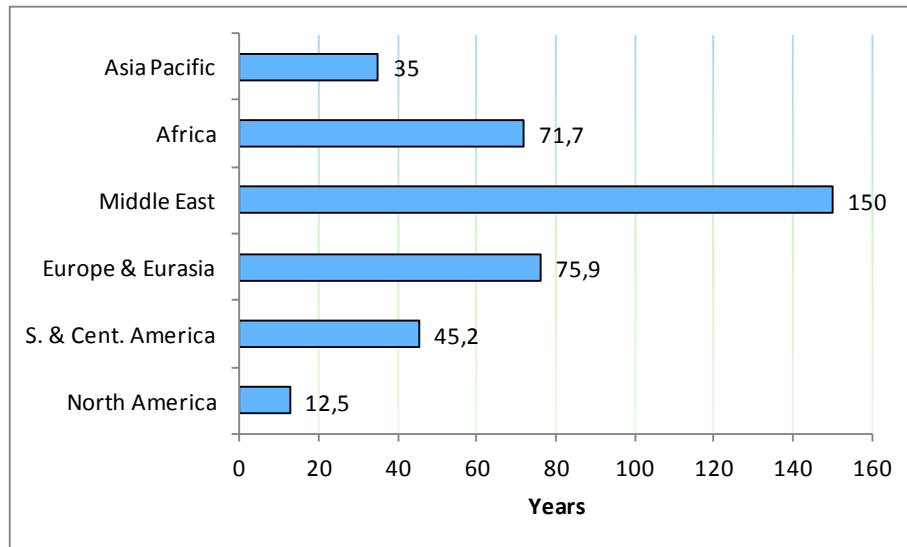


Figure 6. R/P ratio per region, 2011 [31:21]

The Middle East holds the largest share of reserves and has a R/P ratio of over 150 years. Europe and Eurasia has the second highest R/P ratio of 75,9 years. The R/P ratio of proven natural gas reserves worldwide (not including shale gas resources) was estimated 63,3 years at the end of 2011 [31:20]. Compared to the world's oil reserves with a R/P ratio of 54,2 years at the end of 2011 [31:18].

6. LNG value chain

A value chain is a process of activities performed to deliver a product to the market. The LNG process consists of: extraction, production, liquefaction process, shipping, storing and distribution to users either as LNG or converted back to gas with a re-gasification process, see Figure 7 [32].

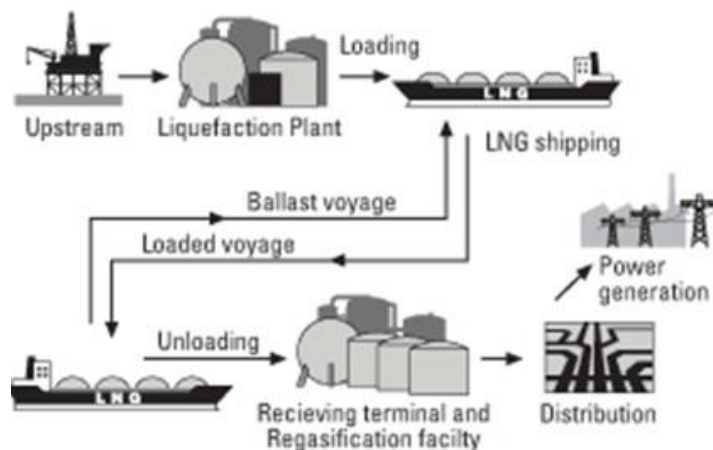


Figure 7. LNG value chain process [32]

Natural gas is extracted both offshore and onshore. After extraction it is transported to a processing facility for purification where any condensates such as water, oil, mud and gases

such as carbon dioxide (CO₂) and hydrogen sulphide (H₂S) are removed. Once gas is received at a liquefaction plant it has to be as close to pure methane as possible. Carbon dioxide and sulphur components can damage the plant's refrigeration units and/or decrease the LNG quality [33:55]. Any traces of mercury from the gas stream are also removed to prevent mercury amalgamates with aluminum in the cryogenic heat exchangers used in liquefaction plants. If not removed it can cause gas leakage and mechanical failure in the heat exchangers [34:2]. Once the natural gas has been purified it is cooled down in stages until it is liquefied. Four liquefaction processes are available today: the C3/MR process, the Cascade process, the Shell DMR process and the Linde process [35].

LNG is stored in insulated storage tanks where it can be loaded and shipped in specially designed refrigerated ships (LNG carriers) to receiving markets. The LNG is stored in individual tanks which are insulated to maintain the cold LNG temperature and to keep the vaporization (boil-off gas) to a minimum. Older LNG carriers do not have a refrigeration systems onboard and use therefore the "boil-off gas" (BOG) as a fuel for the ships [32].

At a LNG receiving terminal the LNG is transferred by pumps to insulated storage tanks, under or above ground, specially designed to hold LNG at a low temperature and minimize evaporation. There will always be some heat leakage causing vaporization of the LNG and these vapors need to be released to prevent the pressure and the temperature within the tanks to rise. The BOG from the storage tanks can be re-liquefied and put back into the tanks or collected and put to use either as a fuel source at the storage facility or as a fuel for the LNG transport ships. In emergencies it may be vented [29].

Underground LNG storage tanks are more environmentally friendly and have high level of safety [36]. Safety and operational consideration of each location determine the tank type used. The different types of LNG storage tanks are:

- Single containment
- Double containment
- Full containment with a steel or concrete roof [37:17].

Single containment tanks are the least expensive design but they need a bounded area around them, between other tanks and equipment, for safety reasons in case of a breach in the inner tank. These tanks take therefore much land space. Less area is needed for double containment tanks because they have a concrete outer wall that can contain the LNG in case of a breach of

the inner wall. Full containment tanks with a concrete roof allow the closest space between tanks and equipment but this design is the most expensive one with about 70% higher cost than for a single containment tank [38:122]. Most tanks built today are full containment tanks [39:2]. For storage of small quantities of LNG (< 700 m³) horizontal or vertical, vacuum-jacketed, pressure tanks are used [40], see Figure 8.



Figure 8. Vertical LNG tanks [41]

For larger capacities than 700 m³ multi-tank installation can be used [40].

7. LNG as a ship fuel

Natural gas is best known as an energy source for cooking, heating and generating electricity. Compressed natural gas (CNG) has been used as a fuel for cars, trucks and buses because natural gas burns cleaner than gasoline and diesel releasing lower emissions of harmful pollutants [42].

LNG has been used as a marine fuel for many years, but mainly as the BOG in LNG carriers before the year 2000 [4:1]. The first ship running on LNG was the passenger ferry *Gultra*, launched 2001 in Norway [43:1]. LNG has proven its safety and technical feasibility as a fuel for ships in the 26 LNG fuelled ships in operation today. These are 15 ferries, five offshore support vessels, three coast guard vessels, one product tanker and two LNG tankers. Most of these ships are operating in Norway [44:26]. Because of new more stringent environmental regulations within Emission Control Areas (ECA)⁴ the use of LNG as a ship fuel has been growing, especially in Europe [4:1]. As of April 2012, 29 new LNG fuelled ships are being built and it is estimated that about 1000 LNG fuelled ships will be in operation in the year 2020 [19:46–48].

⁴ Emission Control Areas (ECA) are shown in Appendix 1 [3:7].

7.1 Regulatory framework

The following rules and regulations exist for the operation of LNG carriers and the handling of LNG as cargo:

- IMO -IGC Code: rules which apply to LNG bunker boats and LNG carriers [45].
- ISO 28460:2010 Standard: Ship, terminal and port requirements that ensures safe transit of a LNG carrier through a LNG terminal and ensures safe transfer of LNG cargo [46].
- SIGGTO: Tanker-to-tanker LNG transfer guidelines [47].

Det Norske Veritas (DNV) issued the first rules Pt.6 Ch.13 "*Gas fuelled engine installations*" in January 2001 based on the development in Norway of ships running on LNG as a fuel [48]. The rules are applicable to all ship types and have been updated several times [49:9].

Interim-Guidelines for gas as a ship fuel (MSC-285(86)) was developed by International Maritime Organization (IMO) in the year 2010. A mandatory IMO code "IGF Code" for the safety of gas-fuelled ships is under development and is expected to enter in to force in the year 2014 and until then the Interim-Guidelines are applied. The IGF Code focuses mainly on LNG as a ship fuel but will cover other liquefied gases and low flashpoint fuels ($<60^{\circ}\text{C}$) [50].

No standards exist for the port and bunkering LNG operations but DNV has initiated ISO TC67/WP10 which is a guideline for LNG bunkering equipment and procedures [49:10].

In addition to existing rules for the use and handling of LNG, port and local state regulations should be followed. To ensure efficient safety for LNG fuelled ships, more stringent risk analysis are required until formal standards and procedures have been issued [3:13].

7.1.1 Air pollution from ships

Pollution from ships is controlled by the IMO through the "International Convention for the Prevention of Pollution from Ships" (MARPOL). As of March 2013, 152 countries were parties to the MARPOL convention with 99,2% of the world's tonnage [51]. The MARPOL convention Annex VI "Regulations for the Prevention of Air Pollution from Ships" sets limits on NO_x and SO_x emission from ships. This annex is voluntary for the members of the MARPOL convention [52] and as of March 2013, 72 countries with 94,3% of the world's tonnage were part of it [51].

The global sulphur limit in fuels is now 3,5% and will be lowered to 0,5% in the year 2020. More stringent limit is for ships within ECA [14:13], see Figure 9.

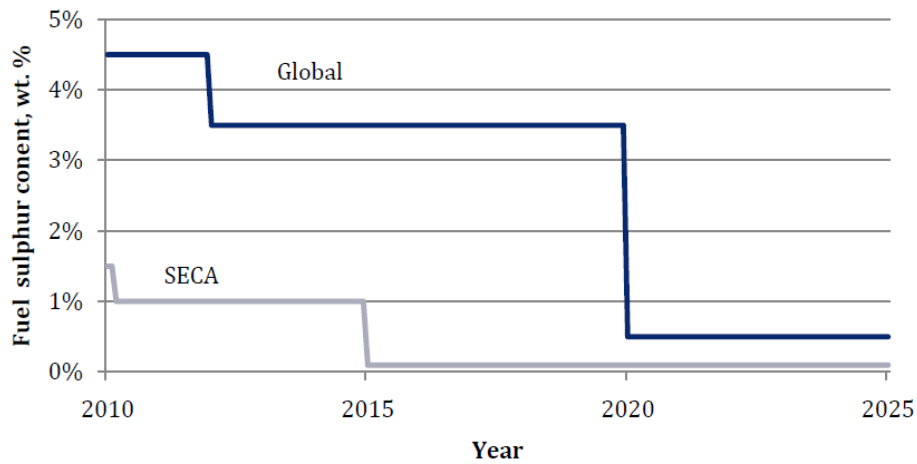


Figure 9. MARPOL Annex VI limits on sulphur content in marine fuels [14:13]

New limits on NO_x emission within the ECA (Tier III) will come in to force in 2016 [14:14] , see Figure 10.

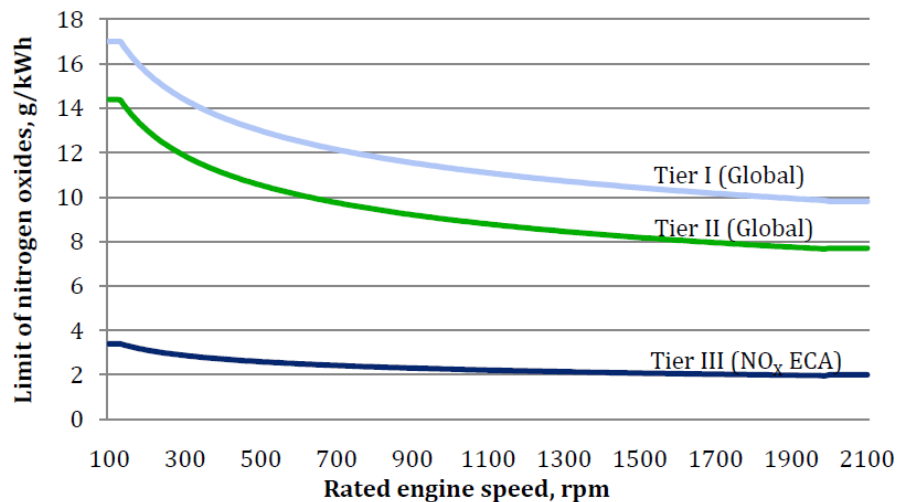


Figure 10. MARPOL Annex VI limits on NO_x emission [14:14]

Tier II is a global NO_x limit that was set in the year 2011. LNG as a fuel fulfills the stringent requirements within the ECA after the year 2016 because LNG emits no SO_x and very little NO_x [20:2].

7.2 Engine options

The main engines today running on LNG as an energy source are dual-fuel engines and lean burn single gas engines. Dual-fuel engines are mainly supplied by Wärtsilä and MAN Diesel whereas Mitsubishi and Rolls-Royce are the main suppliers of gas engines [53:19].

The lean burn gas engines run only on gas. Lean burn means that the air-fuel ratio is high which leads to lower combustion temperatures resulting in lower NO_x formation. It works according to the Otto cycle where combustion occurs with a spark plug ignition. The injection

of gas is at low pressure [54]. This engine is designed to ensure high efficiency and low emission but it does not have the flexibility to run also on fuel oil [55:50].

Dual-fuel engines run either on LNG in gas mode or on conventional oil in diesel mode. They can be designed either as four stroke (low pressure) engines or as two stroke (high pressure) engines [55:49]. The Dual-fuel four stroke engines work according to the Otto cycle in gas mode but a small amount of diesel fuel, less than 1% of the total fuel used, is injected into the combustion chamber (instead of a spark plug) igniting the lean air mixture. The gas is injected at low pressure [54]. Figure 11 shows this process.

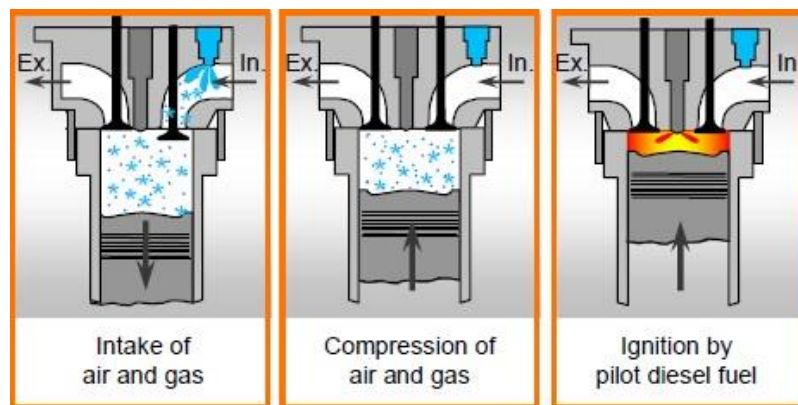


Figure 11. Gas mode operation of a dual-fuel engine [13:11]

The dual-fuel two stroke engines differ in a way that the gas is injected at a high pressure (about 300 bar) together with pilot diesel oil. First the fuel oil ignites and then the gas by the burning fuel oil [55:49]. Dual-fuel engines work according to the normal diesel cycle in the diesel mode. Air is compressed raising the temperature to the ignition temperature of the fuel and ignites when the fuel is injected [54:43]. Figure 12 shows this process.

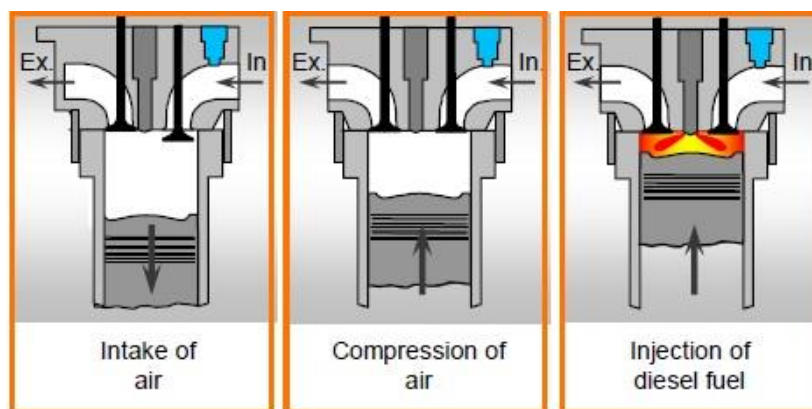


Figure 12. Diesel mode operation of a dual-fuel engine [13:11]

Dual-fuel engines can switch from gas mode to diesel mode on the go at any engine load without any complications and it takes under a second. However transferring from diesel

mode to gas mode is a gradual process and the effect on the engines speed and load is minimal [54:46]. Dual-fuel engines in gas mode have lower load acceptance than in diesel mode and therefore the engines transfer to diesel mode at engine loads over 80%. In addition the engines automatically change to diesel mode if they have been running on engine loads below 15% for three minutes. In alarm situations such as gas system failure the engines switch automatically to diesel operation [13:12]. The efficiency of the dual-fuel engines in gas mode can be about 48,5% [56].

The dual-fuel engines are preferred for ship propulsion where there is limited supply of LNG infrastructure. The main benefit of dual-fuel engines is the fuel flexibility, to be able to run either on LNG or conventional oil depending on the operational pattern, economic factors and the fuel availability. With two systems, dual-fuel engines can achieve full redundancy by using diesel oil as a back-up fuel in case of gas system failure as well as during longer voyages and bad weather where more energy is needed [57].

7.3 Storage tanks onboard ships

According to the current IMO- IGC code, the LNG tanks onboard ships using LNG as a fuel have to be independent tanks type A, B or C. These tanks are self-supporting and are not a part of the ship's hull structure [58:3].

Type "A" tanks are prismatic tanks which are adjustable to the ship's hull making them space efficient. The pressure within the tanks may not exceed 0,7 bar and therefore a complex fuel system with a compressor is needed. The tanks need a full secondary barrier to ensure safety because the construction material used is not crack propagation resistant [58:4]. Figure 13 shows the structure of a type "A" tank.

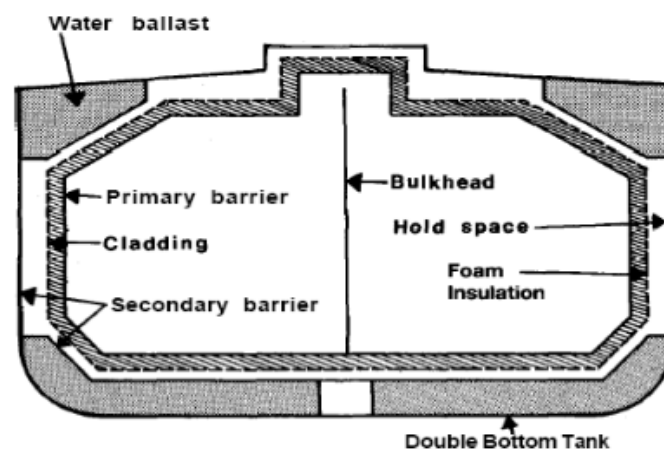


Figure 13. Independent prismatic type "A" tank [58:4]

The most common Type "B" tanks are the spherical (Moss type) tanks, see Figure 14. This design only requires partial secondary barrier. This type of tank are mainly used in LNG carriers [58:5].



Figure 14. Spherical type "B" tank [59]

Type "C" tanks are spherical or cylindrical (pressure tanks) with more than 4 bar design pressure. The cylindrical tanks can be placed vertical or horizontal. Because of the low design stress no secondary barrier is required [58:6]. The advantage of the type "C" tanks are that the pressure increase due to BOG within the tanks is not a problem because they are designed for high pressure which also allows high loading rates. The disadvantage of these types of tanks is the space demand required onboard the ships because of the tanks shape [20]. Figure 15 shows a type "C" cylindrical tank.



Figure 15. Type "C" cylinder tank [17:6]

To minimize sloshing the sphere is the preferable shape of LNG tanks. Cylinders with semi spherical ends comes next and then prismatic shapes [20:4]. Type "C" tanks are the preferred solution for ships with LNG propulsion. The tanks have proven to be reliable and safe and they are easy to manufacture and install [60]. The tank design is under development with the

focus to increase space efficiency [17:6]. The maximum filling ratio of LNG tanks are 95% [18:3].

7.3.1 Placement of LNG tanks onboard ships

The LNG tanks can be placed either above or below deck. It is less expensive and complex to place the tanks above deck. If the tanks are placed below deck then more control is required e.g., the tanks require separate zones from other spaces, a ventilation system, explosion proof appliances and a gas detection system. It is however considered safer to place the LNG tanks below deck in the event of a collision to reduce the risk of damaging the tanks [20:4]. According to DNV rules the location of gas tanks below deck should be as Figure 16 shows.

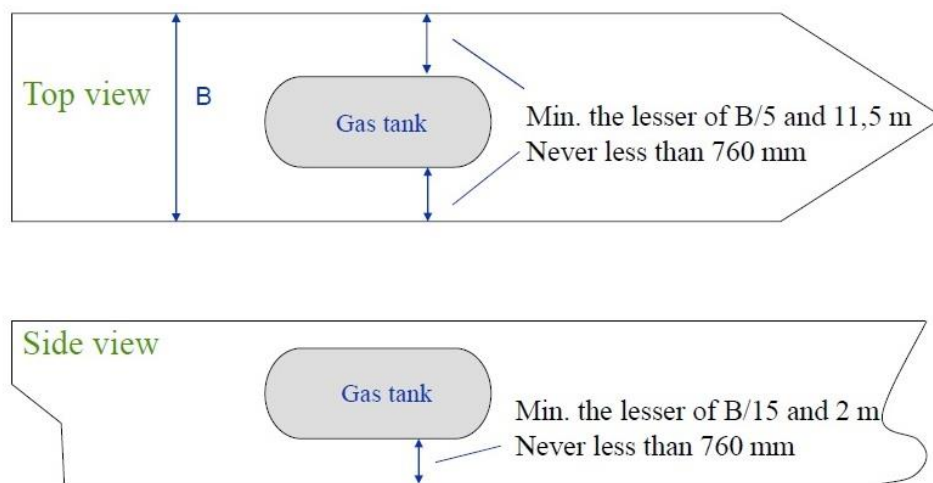


Figure 16. Secure location of gas tanks onboard a ship [49]

Ships fuelled only with LNG need to have at a minimum two separate LNG tanks, each with its own separate tank space. Ships with dual-fuel LNG propulsion only need one LNG tank [61:101].

7.4 Safety issues with LNG

LNG operations have an excellent safety record with LNG tankers in operation for 50 years and LNG as a marine fuel since the year 2001 [3:13].

In liquid state LNG is not explosive and in case of a spill it would evaporate quickly because in gaseous form it is lighter than air [55:108]. The risks of LNG depend on its state at the moment of release [62]. LNG spills over water are very different to LNG spills over land. Figure 17 displays the hazards resulting from a spill over water [12:176].

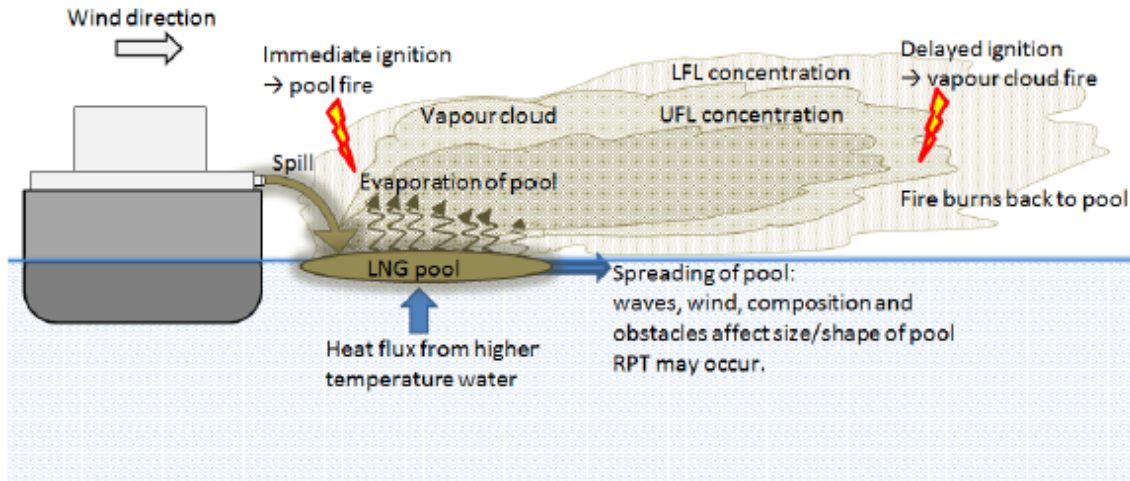


Figure 17. LNG spill over water

During normal ship operations the likelihood of a LNG spill is very low because of the required safety systems onboard [4:3]. Storage, transport and the use of LNG involves specific safety risks that have to be identified and assessed for each case scenario, in relation to the probability of it occurring and the severity in case it does, to ensure sufficient safety levels [3:13]. The main risk outcomes and safety concerns with the release of LNG are:

- **Cryogenic damage**

Because of LNG's low temperature at $-162\text{ }^{\circ}\text{C}$ it is considered a cryogenic liquid. Damage such as metal embrittlement, cracking and structural failure can be caused to the ship or infrastructure materials that cannot handle contact to such cold temperatures. Special steels exist that do not suffer from a LNG spill and can be applied to sensitive areas such as LNG loading areas [62:2].

- **Asphyxiation**

A large release of LNG close to people or a spill in enclosed non ventilated spaces could cause asphyxiation if there becomes large concentrations of natural gas in air resulting in a deficiency of oxygen [12:176].

- **Pool fire**

If there is an immediate ignition of a LNG spill a pool of fire occurs. Once the pool of liquid starts to evaporate, the mixture of air and LNG vapor over the pool will burn on ignition when the LNG vapor is within the flammable range of 5-15% mixture with air. As the pool of LNG continues to evaporate it provides fuel to the fire. With concentration less than 5%, the lower flammability limit (LFL), the LNG vapor would not burn because there

is not enough natural gas as fuel and with concentration higher than 15%, the upper flammability limit (UFL), there is insufficient oxygen to support combustion. Some experts believe that pool fires on water pose the greatest LNG hazard and would most likely result from events like collision where metal on metal provides an ignition source [12:175].

- **Vapor cloud fire**

If there is a delayed ignition of the LNG vapor after a spill a vapor cloud fire occurs. Then a vapor cloud within the flammable range of 5-15% mixture with air is ignited away from the initial LNG spill causing a fire. The fire can burn back to the source of the LNG spill as a "fire ball" (burning fast) or as a "flash fire" (burning slow) [63]. Since these LNG fires generate fairly low pressures they are unlikely to cause pressure damages [12:175].

- **Explosions**

LNG in liquid state is not explosive. If a confined fuel-air cloud forms in spaces like the ship's hull or tank a damaging overpressure can emerge from a vapor cloud fire. With high degree of confinement, a strong mixture with air and a large source of ignition there is a potential for an explosion [63].

- **Rapid phase transition (RPT)**

If LNG at high pressure (higher than atmospheric pressure, cold LNG) comes in contact with much warmer water RPT can occur. The liquid transforms quickly into gas resulting in explosive boiling and similar is to an explosion, shock waves and over pressure can be formed. No combustion is involved [63].

7.5 Supply of LNG in Europe

For the future growth of LNG as a ship fuel its availability has to be secure. First of all large-scale import terminals have to be constructed in Northern Europe. These terminals are usually built to import gas to feed the national gas network, but to use LNG as a ship fuel these terminals would need to include facilities to load feeder ships and/or trucks. For a reliable and secure supply network of LNG infrastructures a small-scale and medium-scale intermediary LNG terminals or storage facilities will be needed. They can be LNG tanks onshore or as LNG bunkers and/or feeder vessels offshore [12:16]. Definition of terminal sizes are given in Table III.

TABLE III.
DEFINITION OF LARGE, MEDIUM AND SMALL-SCALE LNG TERMINALS AND SHIPS [12:16]

Activity/Aspect	Large scale	Medium scale	Small-scale
On shore storage capacity	Import terminal $\geq 100,000 \text{ m}^3$	Intermediary terminal 10,000- 100,000 m^3	Intermediary terminal $< 10,000 \text{ m}^3$
Ship size, LNG capacity	LNG carriers 100,000 – 270,000 m^3	LNG feeder vessels 10,000-100,000 m^3	LNG bunker vessels 1,000-10,000 m^3 LNG bunker vessels/barges 200 – 1,000 m^3
Tank trucks			40 – 80 m^3

End users are served through these terminals with either trucks, pipelines, jetties (pier for mooring), bunker barges and feeder vessels, see Figure 18 [12:16].

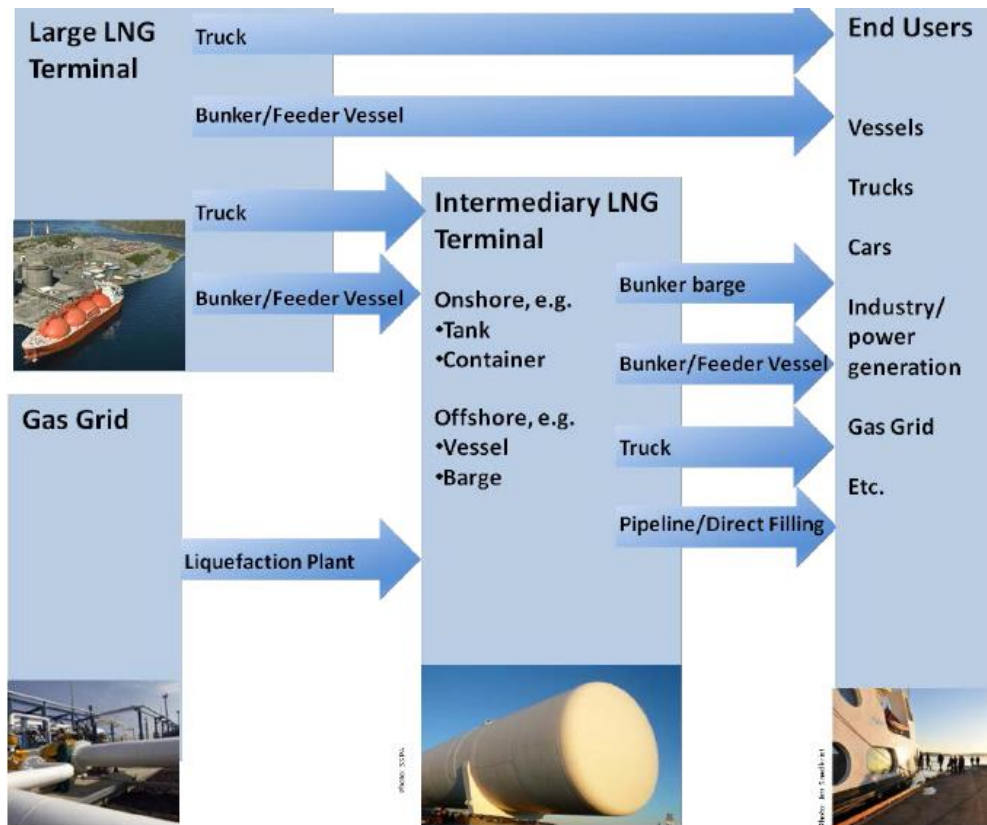


Figure 18. Supplying arrangements of LNG to end users.

Table III and figure 18 shows that there are many ways to supply LNG to end users depending on the terminal type.

7.5.1 Bunkering of ships

Bunkering of ships would be in port or offshore using feeder vessels [12:16]. The main bunkering methods used are: straight from Terminal-to-Ship via pipeline, Ship-to-Ship and Truck-to-Ship, see Figure 19 [12:18].

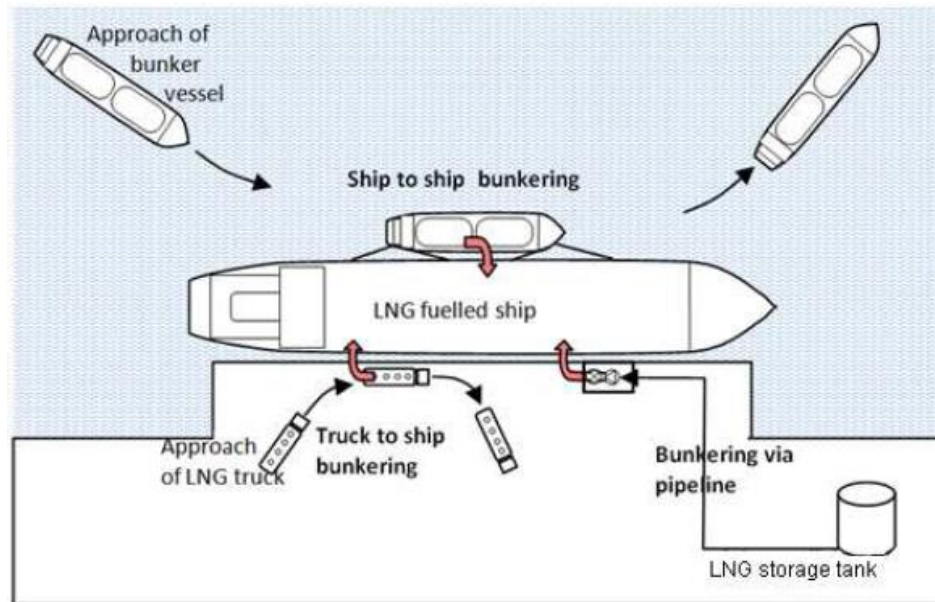


Figure 19. Bunkering methods for ships

All these bunkering methods can be used parallel, as complementary solutions during peak LNG demand and when serving different ship types [12:18].

7.5.2 Terminals in Europe

The North European countries are currently focusing on small-scale distribution and operation of LNG, with small LNG terminals. Small scale infrastructures have been established in Norway since the year 2000 [12:10].

There is a limited liquefaction capacity in Northern Europe. Nine liquefaction plants exist today, five in Norway, one in Finland and three in Russia. Four more are planned and proposed over the next four years [64:72]. Most of the world's capacity is located in other parts of the world (Figure 4 in chapter 5.1). The European and Eurasian countries import LNG mainly from Qatar, 48% of the total LNG imported in the year 2011 [31:28]. Current and planned LNG infrastructures in Northern Europe are shown in Figure 20.

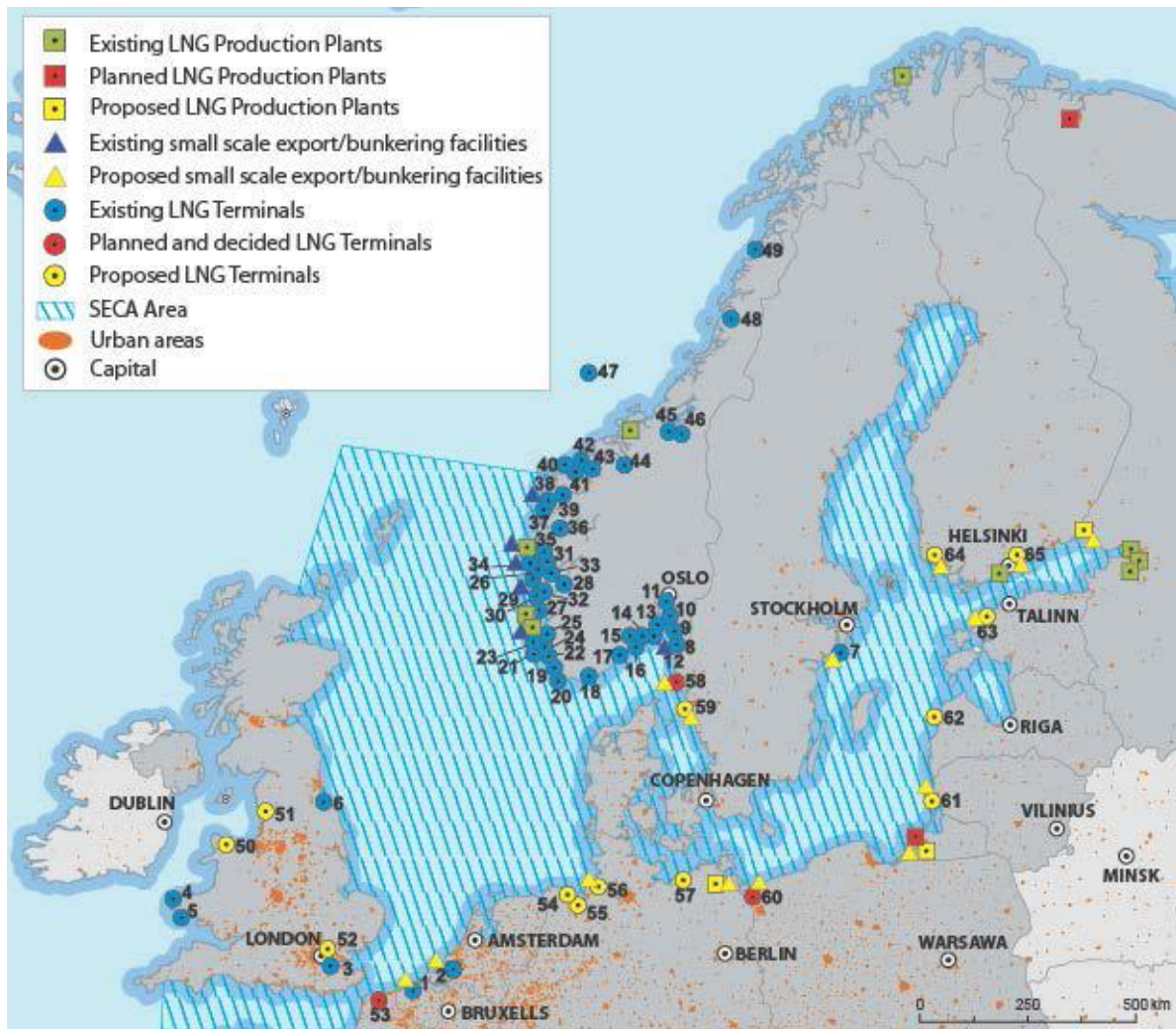


Figure 20. Current and planned LNG terminals and production plants within the SECA [12:16]

Large LNG import terminals exist in the United Kingdom, the Netherlands, and Belgium. It is estimated that large import terminals will be established by 2020 in France, Finland, Germany and Poland. Additional terminals are expected in the United Kingdom due to increased demand of LNG [12:17].

A LNG import terminals usually includes offloading berths and ports, LNG storage tanks and where there are gas grid vaporizers (needed, to convert LNG back to gas) and a pipeline linked to the local gas grid [32].

7.6 Main benefits of using LNG as a fuel

Switching to LNG as a ship fuel has some benefits both environmental and economic.

These benefits can act as drivers for ship owners to switch to LNG as a fuel. In this chapter the main benefits are described and other influencing factors that could lead to a switch to LNG propulsion.

7.6.1 Emission reduction

The main environmental pollutants that ships emit are CO₂, SO_x, NO_x and PM [17:3]:

- Carbon dioxide (CO₂) is a greenhouse gas that contributes to global warming and a reduction of CO₂ from ship propulsion is only possible by burning less oil or switching to alternative fuels.
- Sulphur oxide (SO_x) combines with water and forms "Acid rain" that can be harmful to aquatic animals, plants and infrastructure.
- Nitrogen oxide (NO_x) also forms "Acid rain" when combined with water. This pollutant can be harmful to humans where it can damage the lungs and cause asthma and heart disease. NO_x contributes greatly to smog and ozone formation.
- Particulate matter (PM) is the soot that comes from the ships exhaust. It can cause respiratory problems and cancer. PM can also cause metal corrosion on ships. The smaller particles (2µm-10µm) can be transported with wind over large distances.

Using LNG as a fuel for ships offers great environmental advantages in emission of these four pollutants compared to conventional fuels, see Figure 21.

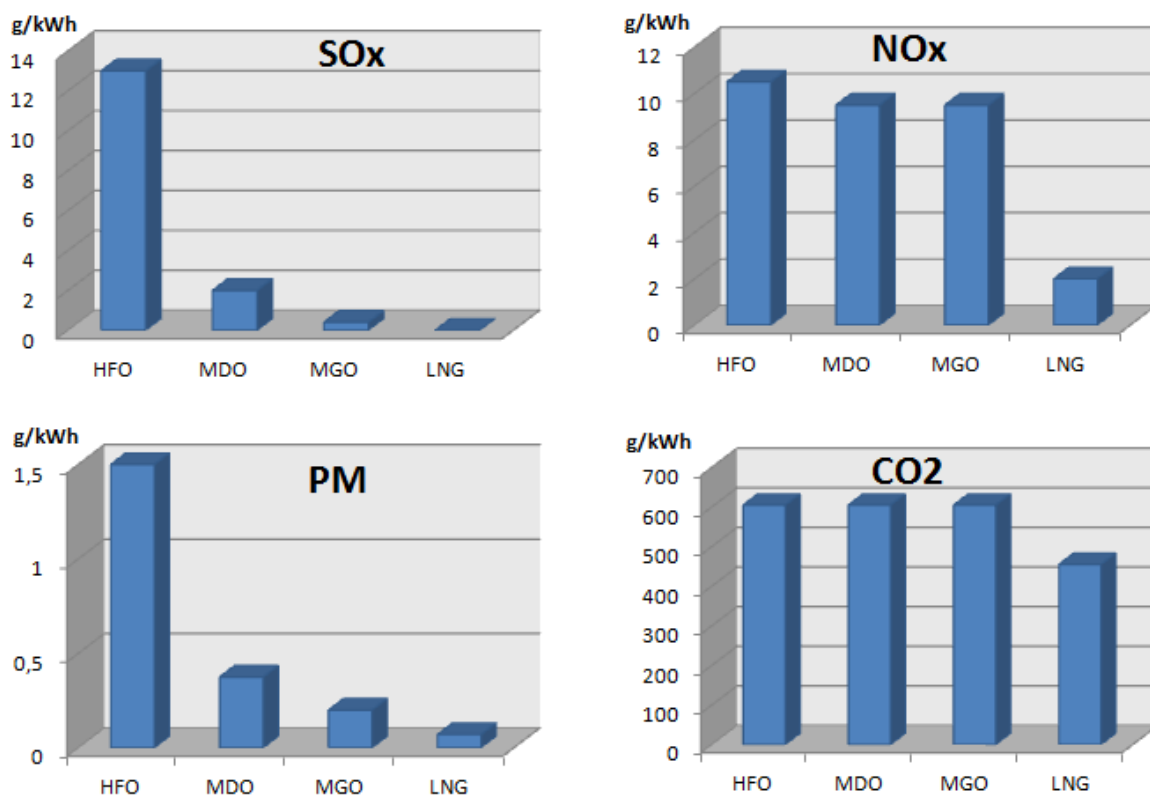


Figure 21. Emission comparison of different fuel types [20:2]

LNG as a fuel has very low concentration of SO_x since it is removed from the fuel when liquefied. PM emission is almost nothing, NO_x is reduced by 85-90% and CO_2 by 20-25% compared to conventional oil because of the low carbon to hydrogen ratio of LNG [4:170], [20:2]. In countries where a carbon tax has been imposed on fuels a reduction in CO_2 emission can be of economic interest.

7.6.2 Lower fuel cost

Switching to LNG as a fuel can have economic benefits because LNG is expected to cost less than MGO and HFO [6:3], see Figure 22.

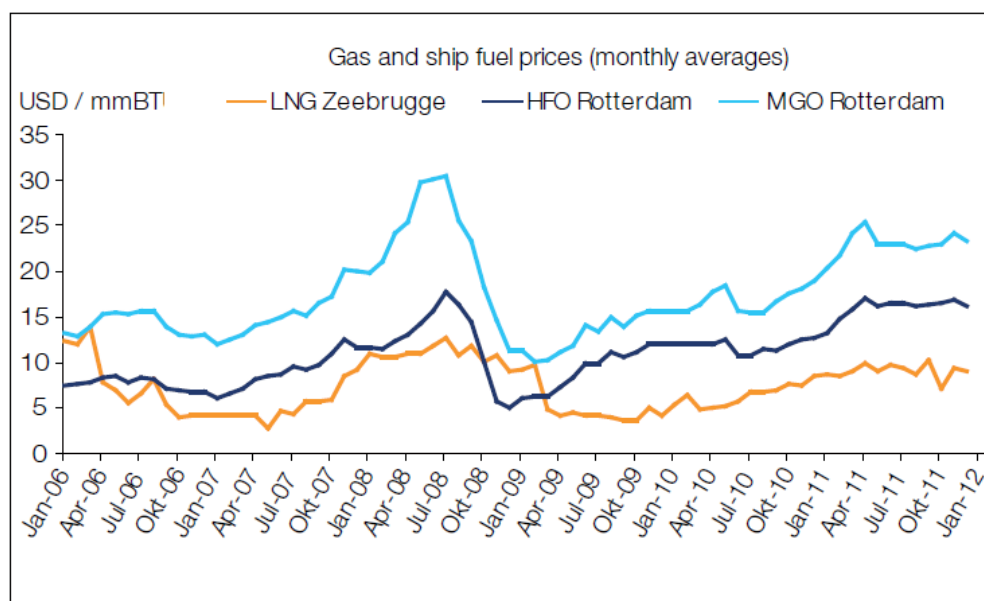


Figure 22. Gas and oil prices past years [6:3]

Fuel prices should always be compared based on energy content instead of mass because more energy is in one tonne of LNG than in one tonne of MGO and HFO [12:64]. Figure 22 shows that LNG prices are not as unstable as MGO and HFO prices and the LNG price is much lower than the MGO price and only over few months it exceeds the HFO price.

Today there are great variations of LNG prices depending on geographic regions. North America has the lowest natural gas price because of increased gas supply due to the growth of shale gas availability [3:10]. Future fuel prices are always hard to predict, but experts assume that oil prices will remain high in the coming years and as oil resources decline prices will rise [65:15]. As of now proven natural gas reserves have higher R/P-ratios than oil and are increasing at a faster rate [31:18–20]. With shale gas increasing the world's natural gas supply the price advantage of LNG compared to conventional oil is expected to be maintained in the future [17:4].

7.6.3 Energy reduction

It is possible to utilize the low LNG temperature to cool down fish storage tanks in fishing ships [12]. This is done by utilizing the waste cold recovery (WCR) from the LNG re-gasification process [66:11]. This would be an economic and an environmental benefit for the fishing ship owners because it could result in less usage of conventional refrigeration systems, reduce the energy need and the cost of freezing fish onboard, and reduce emissions even more [7:4].

7.6.4 Other influencing factors

Global warming is influencing fisheries where there have been changes in productivity, invasion of alien species, distribution shift and changes in abundance, decline in primary production and negative effects of increased acidity [2:5]. The ocean absorbs CO₂ from the atmosphere, now at a faster rate than ever before, causing the pH balance of the ocean to decrease⁵. This results in rising ocean temperatures and acidification that can radically alter the marine ecosystem [2:5],[14:20]. To mitigate these effects emission of CO₂ and other GHG has to be reduced.

In Europe financial incentives are mostly used to reduce GHG emission, that is based on the method that those who pollute should pay for it [68]. Some countries have implemented a carbon tax where a fee is levied on fossil fuels based on its carbon content. This encourages reduction in consumption and increase in energy efficiency. Carbon tax can help promote cleaner alternative fuels such as LNG [1].

Fish consumers are today becoming more concerned with the carbon footprint associated with products [7:1]. The carbon footprint is related to how much GHG are emitted from the use of fossil fuels every day. For fishing ships the amount of fuel oil burned is the largest contributor in the total emission of GHG [2] and to lower the carbon footprint from fishing the ships need to burn less fuel oil or switch to a cleaner alternative fuel such as LNG [17:3].

⁵ pH is a measure of the hydrogen ion activity [67].

7.7 Main disadvantages of LNG as a fuel

The main disadvantages and possible obstacles for ship owners to switch to LNG as a ship fuel are explained in this chapter.

7.7.1 High investment cost

To be able to use LNG as a fuel the ships need purpose-built or modified engines, a system of special LNG fuel tanks, a vaporizer and a double insulated piping because of LNG properties and for safety reasons. The investment cost of a new built LNG fuelled ship is estimated to be about 10-20% more than of a conventional fuelled ship. The added investment cost will vary significantly between ship types and the cost it is expected to decrease in the future as more LNG fuelled ships are constructed [3:8–10].

The cost of converting a ship is more expensive than the added investment cost imposed on a new ship running on LNG propulsion. The equipment cost of converting an existing engine can be similar to buying a new engine, but the installation can be easier and cheaper. The largest expense of a conversion is installing the LNG tanks, piping, safety system and ship modifications. This cost can be five times the cost of the engine conversion or engine replacement. The actual cost can vary between the ship type, size and configuration [53:19].

7.7.2 More space demand

LNG tanks and fuel system require more space onboard ships compared to conventional oil. LNG has lower energy density compared to MGO [17:5], see Table IV.

TABLE IV.
ENERGY DENSITY RATIO FOR MGO AND LNG [16], [14:7]

Fuel	Lower Heating Value MJ/kg	Density kg/m ³	Energy Density MJ/m ³
MGO	42,6	836	35.614
LNG	48,6	440	21.384
- LNG/MGO energy density ratio for given volume = 1,6			

This means that LNG needs about 1,6 times the volume compared to MGO to give the same amount of energy [17:5]. The total volume needed for the tank and the tank room is expected to be about 2,5 to 4,0 times more than for conventional oil as a research conducted by Hellén in 2009, referred to in the study *"Life cycle assessment of marine fuels"* suggests [14:8]. Figure 23 shows the distribution of extra volume needed.

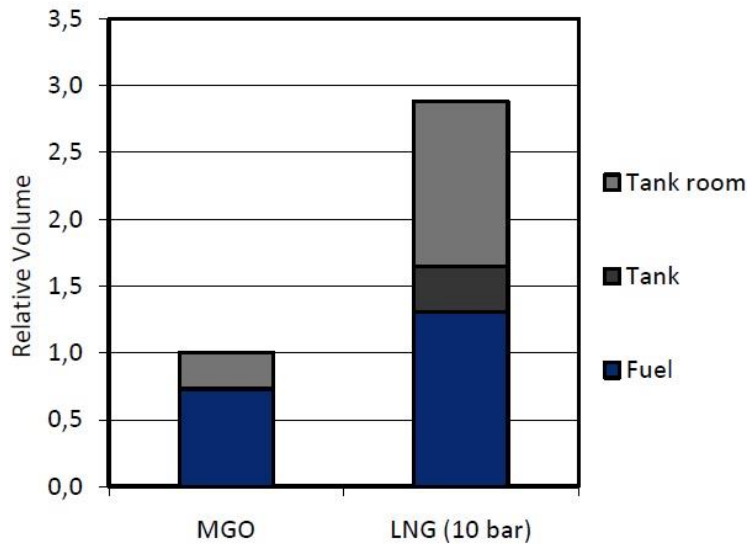


Figure 23. Storage volume for MGO and LNG [14:8]

Whether this reduces the cargo capacity onboard ships depends on the ships type, fuel tank type and the location potential of the LNG tanks onboard the ships [12:60].

7.7.3 Methane slip from engine

With gas and dual-fuel engines running on Otto cycle process in gas mode some methane slip occurs, i.e. uncombusted methane slips through the engine, especially at low engine load. The GHG effect of methane is stronger than of CO₂, i.e. one kg of methane released to the air corresponds to 21-25 kg of CO₂. But the volume of the methane slip from the engine is so small that the effect is limited and the total reduction of CO₂ by using LNG as a fuel compared to conventional oil would still be within 20-25% [3:15]. Even so the methane slip from gas engines has to be minimized and engine manufactures are working on overcoming this problem [12:60]. If not it could become a concern for ship owners in countries where taxes are set on GHG emission [61:103].

7.7.4 Lack of infrastructure

The fuel has to be available for the ship owners being willing to switch to LNG as a fuel and currently there is insufficient LNG infrastructure. The ship owners need to be sure that there is a supply of LNG before they switch to LNG propulsion and the providers of LNG need to be sure of sufficient demand before an infrastructure is established, resulting in a chicken and egg problem. Recommendations from the DMA-report on how this problem could be solved is that ports authorities, ship owners, local communities and other stakeholders work together on assessing the existing and future demand for LNG for the ships at ports and plan and establish the LNG infrastructure needed [12:192]. As more ship owners are willing to switch to LNG propulsion the infrastructure will grow making LNG supply to ship owners more secure [12:29].

8. The Icelandic fishing fleet

The Icelandic economy is very dependent on the fishing industry both as a food source for its people and by providing export income. In 2011 the fishing sector accounted for about 38% of the total export earnings and 11% of GDP. The sector is also very important to the community as it, in 2011 provided jobs to about 5% of the work force or 9.000 people. Even though the fishing quotas⁶ have been reduced, oil prices increased and more levies placed on the industry the EBITDA of the Icelandic seafood industry companies has been high [8:5].

The Icelandic fishing fleet consists of trawlers, decked vessels and undecked vessels. The total number of fishing ships in Iceland registered at the Icelandic Maritime Administration at the end of the year 2012 were 1.690, with 35 ships increase from the previous year. Decked vessels were 778 with a combined size of 89.275 gross tonnages (GT), 56 trawlers were registered with a total size of 72.701 GT and undecked vessels were 856 with 4.110 GT [69]. Figure 24 shows the total number of ships since the year 2006.

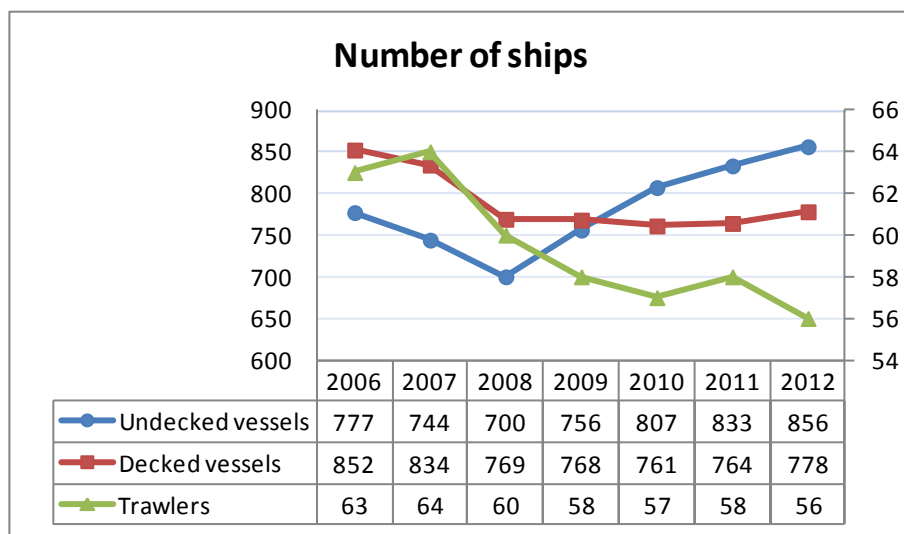


Figure 24. Number of ships from 2006-2012 [69]

The number of undecked vessels have been increasing over the past years but decked vessels and trawlers have been decreasing. The reason for this reduction can be declining quota and increased oil prices [70:6].

The Icelandic fishing fleet is getting old with an average age of 24 years and five months at the end of year 2012. The average age of decked vessels was close to 23 years, undecked vessels close to 26 years and the trawlers average age was about 27 years [69]. The average

⁶ Quota: The Icelandic government implemented the Quota system that is used to manage fisheries of fishing stocks around Iceland.

age has been rising since the year 2003 and more rapidly since the economic crisis in 2008, see Figure 25.

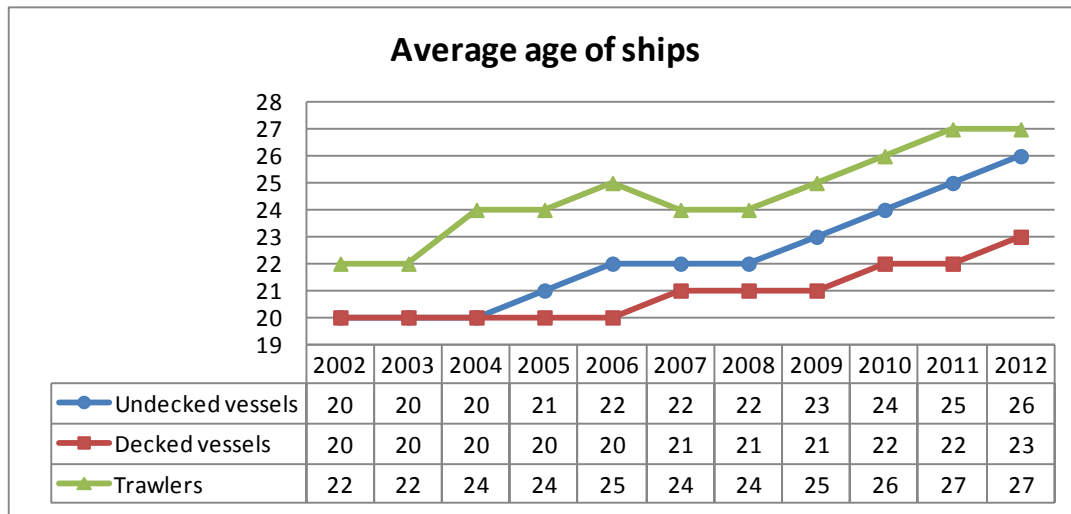


Figure 25. Average age of ships from the year 2002 [69]

The increased average age may be attributed to the lack of resources to invest in new ships and the uncertainty with the Quota system [70:6],[71:20].

8.1 Oil consumption of the fleet

The fishing industry is quite energy demanding and in Iceland the fishing fleet is the second largest consumer of oil after vehicles and equipment, see Figure 26.

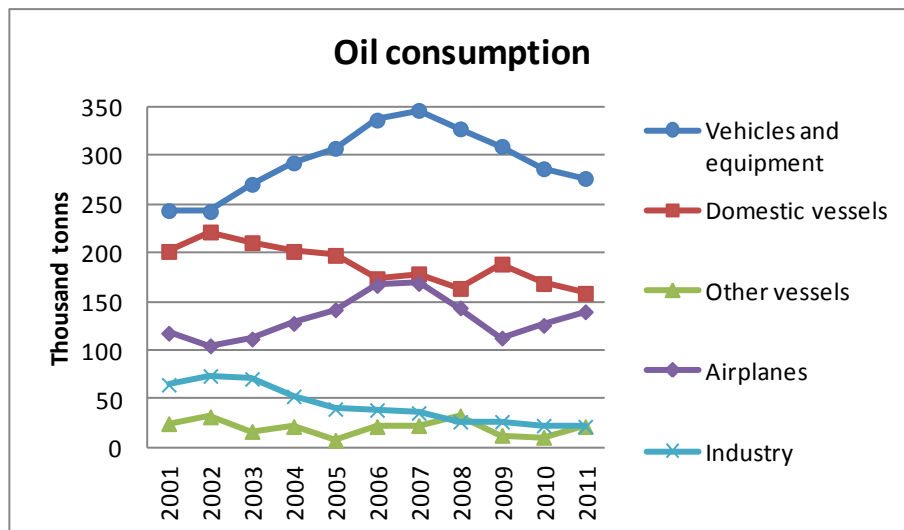


Figure 26. Oil consumption of different users [72:21]

Over the past years large fluctuations have been in the oil consumption of the fishing fleet as Figure 27 shows.

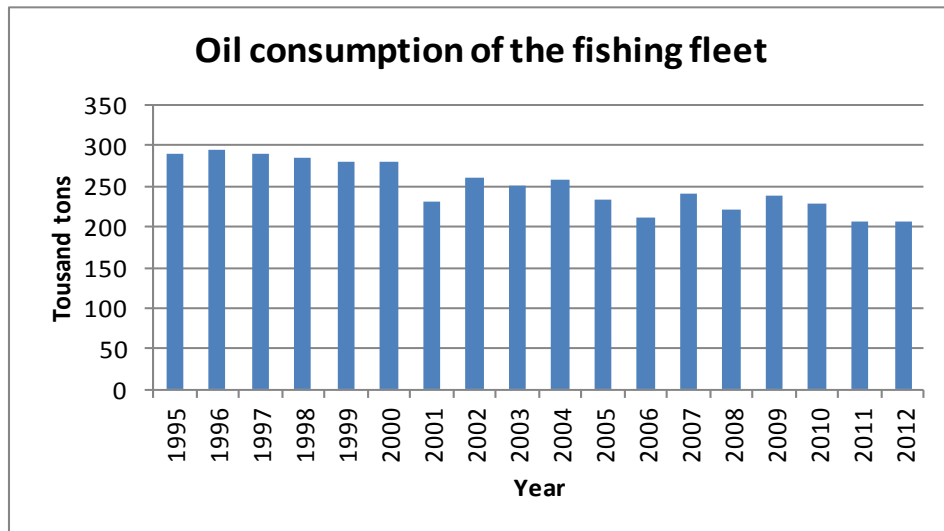


Figure 27. Oil consumption of the fishing fleet from the year 1995 [65:21]

Oil consumption has decreased since the year 1996 because of less usage of fishing ships due to declining catches in international waters and reduced fish catch. The high reduction from the year 2009 is due to less usage of fishing ships because of the economic crisis in 2008 [72:22]. The oil consumption of the fishing fleet has been about 150-170 thousand tons of MGO and if the oil bought abroad is included the oil consumption is about 200 thousand tons [9:17].

There are many factors that influence the oil consumption of fishing ships, e.g. the ships size and shape, engines and technical equipment, the size and type of fishing gear, the type of fish caught, distance to fishing ground as well as weather and sea currents [72:24].

Of the fishing fleet total oil consumption, trawlers and processing vessels account for half but they only catch about 16% of the total catch. Pelagic vessels account for 25% of the total oil consumption and they catch about 67,5% of the total catch. Fuel use coefficients, kilogram of oil per kilogram of fish landed are used to show the oil consumption in relation to fish caught, see Appendix 2 [72:21].

Fishing gears such as line and net are the most fuel-efficient methods and trawl fishing is the most energy demanding. Some fish types cannot be caught without using trawling so switching to more energy efficient fishing methods is not an option, but it can be applied for other fish types. For the fishing industry the cost of oil is the second highest operational cost after labor cost and therefore there is a strong incentive for oil savings [72:24].

Some measures have been developed to reduce the oil consumption of ships, such as:

- to install energy saving systems that can reduce oil use by 5-10% by monitoring and analyzing the oil use of the ship [73:14]. The Icelandic company Marorka are leaders in energy management solutions that optimize fuel consumption by maximizing the ships energy efficiency [74].
- by analyzing the energy savings of different fishing methods, 30% savings of used oil for the same amount of fish caught could be gained.
- utilizing the lost heat from e.g. the cooling systems and flue gases from the main engine can reduce energy use [73:14].
- to use renewable energy instead of oil e.g. biodiesel produced from rapeseed. An experiment production has started in Iceland where biodiesel has been produced from rapeseed and the harvest has given rise to further consideration [73:14],[11:30].

8.2 Oil price development

In recent years the world's market prices for oil have increased and have been historically high from the year 2008. The main cause for this increase is the growing need for oil in the world, mainly in China and other developing countries [65:21]. Increased oil prices result in higher emphasis on energy savings and other energy sources [65:15]. Figure 28 shows the average price of MGO at the Rotterdam market from the year 1991.

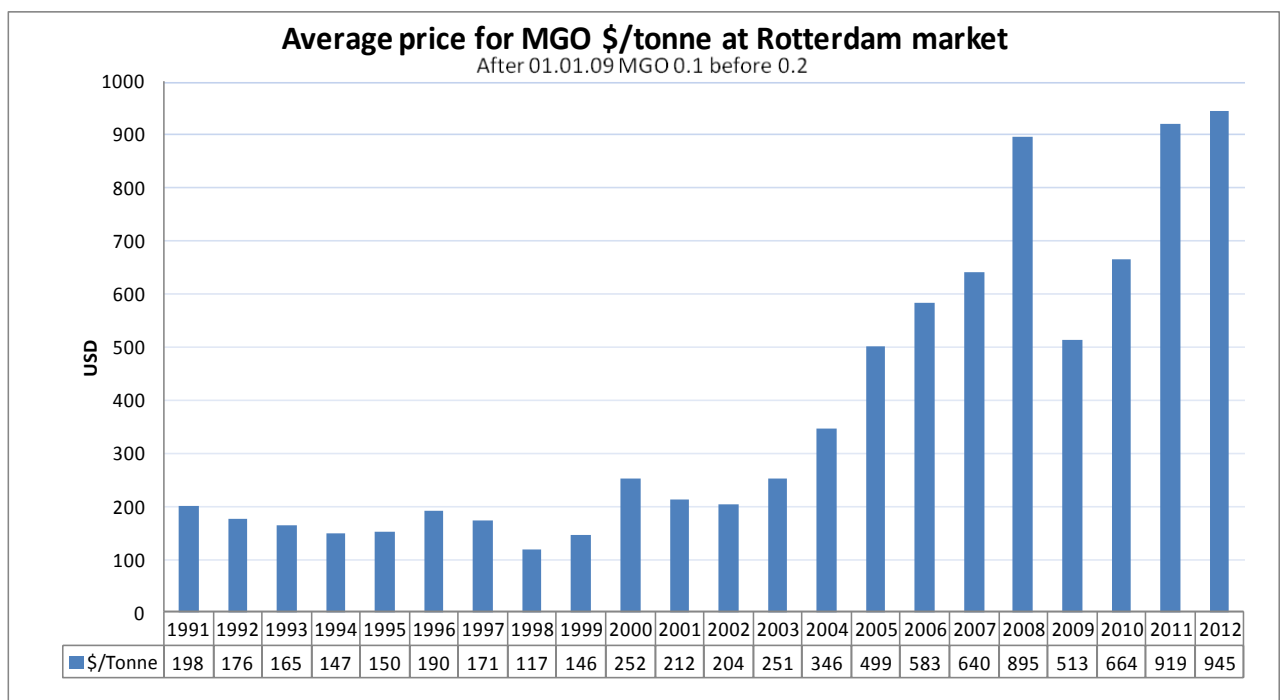


Figure 28. Average MGO price at Rotterdam market from the year 1991 [75]

Such high increases in oil prices influences the whole economy and reduces economic growth. Since oil is the second highest expense after labor cost in the operation of a fishing ship, rises in oil prices can influence the profitability of fisheries [72:24]. The changes in oil prices and money exchange rate have had a major influence on the oil price to the Icelandic fishing ship owners, see Figure 29.

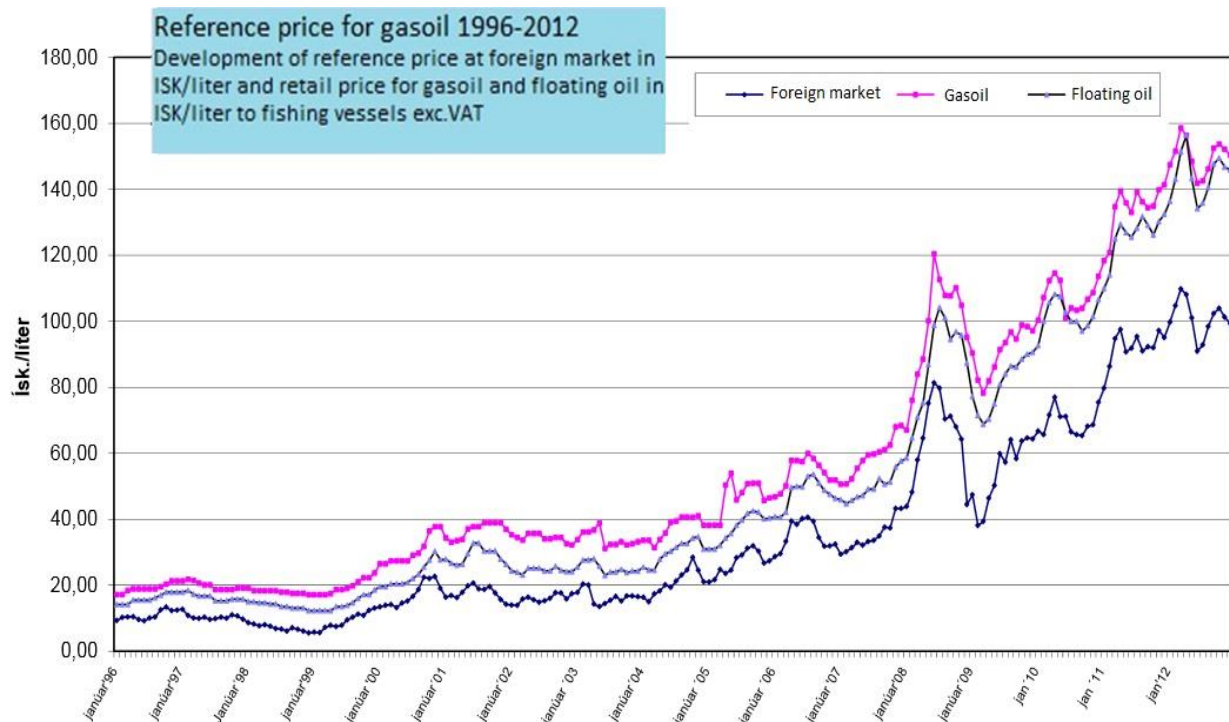


Figure 29. Reference price of gasoil from the year 1996 [10]

Another factor that has affected the price of oil to the fishing ship owners in Iceland is the carbon tax that came in to force the 1.January 2010 with law no. 129/2009 about Environmental and Resource taxes. This carbon tax is imposed on all liquid fossil fuels. The fuels that fall under this law are gas- and diesel oil, gasoline, airplane- and jet fuel as well as fuel oil. The amount of the fee are different for each fuel and depends on its carbon content [11:22]. The carbon tax is 5,75 ISK⁷ per liter of gas- and diesel oil; 5,0 ISK per liter of gasoline; 7,10 ISK per kilogram of fuel oil and 6,30 ISK per kilogram of natural gas and other gaseous hydrocarbons. Under this law the parties that are taxable are those who import or produce in the country the products which are chargeable under this law [76]. The carbon tax is the government's economic instrument to imprint the message that it pays to reduce CO₂ emission [11:3].

⁷ 1 EUR= 164,9 ISK according to Central Bank of Iceland 28.02.2013

8.3 Emission from the fleet

There can be great annual changes in emissions from the fishing industry that reflects its inherent nature [77:22]. The GHG emission from the fishing industry as a whole in 2009 was 656 Gg CO₂-equivalents with an 11% increase from the year before [11:13]. Most of this emission came from the fishing fleet or 603 Gg CO₂-equivalents [78]. According to the Icelandic Government Action Plan on climate issues, the goal is to reduce GHG emission from the fishing industry down to 450 Gg CO₂-equivalents before the year 2020. Based on GHG emission from 2009 the fishing industry is emitting more than the Emission Plan had predicted, see Figure 30 [11:13].

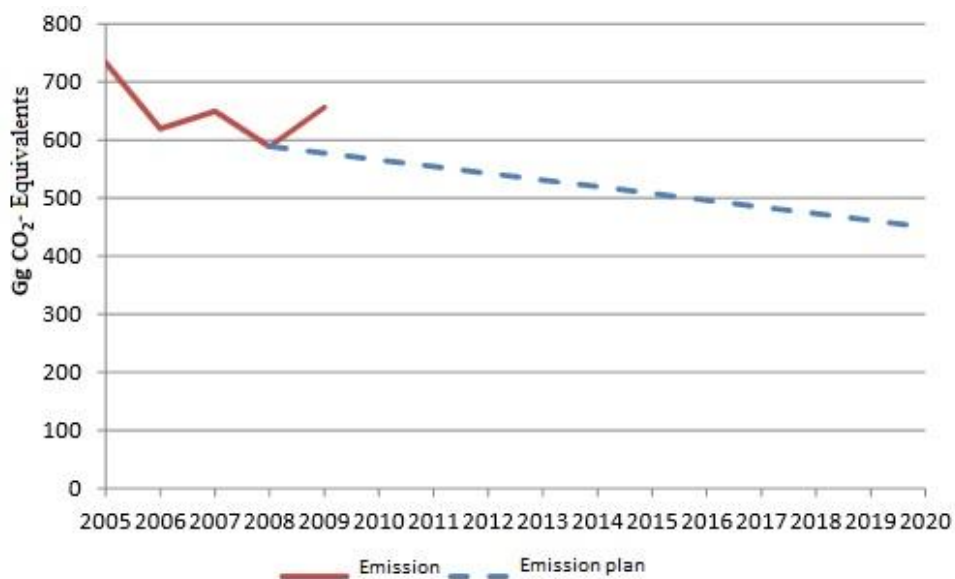


Figure 30. GHG emission from the fishing sector.

The main sources of CO₂ emissions in Iceland comes from industrial processes, road transport and commercial fishing [77:19]. The fishing fleet emitted 540 thousand tons of GHG in the year 2010 of that 535 thousand tons was CO₂ emission [78]. This was an 11% reduction from the year 2009 and was the effect of recession in the economy since 2008 [77:42]. The total GHG emission from the fishing fleet alone in 2010 accounted for 12% of the total GHG emission in Iceland and 15% of the total CO₂ emission [78].

Iceland is a part of The United Nations Framework Convention on Climate Change (UNFCCC) and is therefore committed in taking action to reduce GHG emissions. Under this convention falls the Kyoto Protocol where Iceland commits to a binding obligation to keep GHG emission within certain emissions allowances [77:23].

Iceland is a part of IMO and the MARPOL convention, but has not accepted Annex VI regarding air pollution from ships. According to The Icelandic Maritime Administration is this causing problems in sale of oil to foreign ships and there is a risk that it would not be possible to sell ships out of the country if the ships engines do not meet the provisions of the annex. It can also inhibit the Icelandic ships movements not having certifications of fulfilling the annex requirements [79]. The Director at the Department of Oceans, Water and Climate at the Ministry of the Environment and Natural Resources in Iceland claims that even though the Annex VI has not been validated it does not mean that it has not been approved, the validation process can be long. He also states that many provisions within International Conventions are transposed through the European Economic Area (EEA) agreement that Iceland is a part of, see e-mail in Appendix 10.3. One of those provisions is the regulation for liquid fuels that set requirements on the sulphur content of MGO and as of now the maximum is 0,2% [80] and that meets the global requirements of Annex VI.

9. LNG as a ship fuel in Iceland

To assess whether it would be a feasible option for the Icelandic ship owners to switch to LNG as a ship fuel a feasibility study was conducted. The ships selected for the study are ships in full operation owned by the fishing company HB-Grandi. It is assumed that HB-Grandi would want their ships to run on dual-fuel propulsion, using LNG as a main fuel and MGO as a back-up fuel to have fuel flexibility and security.

To conduct the feasibility study the fuel cost of MGO and LNG in Iceland had to be established. The two following chapters explain how the fuel prices were estimated. Note that all prices in this study are in EUR and excluding VAT. Cost information received in ISK was changed to EUR according to the exchange rate at the Central Bank of Iceland 28. February 2013.

9.1 MGO price in Iceland

The average price of MGO last year (2012) from the fuel sale company N1 in Iceland was 0,872 €/liter⁸. One tonne of MGO contains 1196,2 liters⁹. The average price per tonne last year was:

$$1196,2 \text{ liters} * 0,87 \text{ €/liter} = 1043 \text{ €}$$

The oil prices in Iceland have been increasing, as chapter 8.2 explains. MGO price increases from the fuel sales company N1 for the last three years is shown in Figure 31.

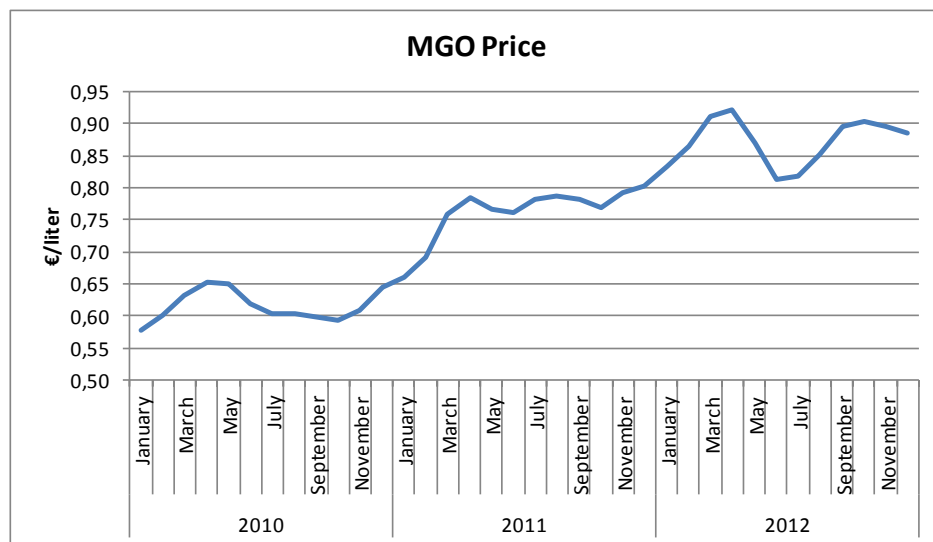


Figure 31. MGO price at N1 in Iceland for the years 2010-2012

⁸ Information received on 14.02.2013, from Magnús Ásgeirsson Fuel Purchasing Manager at N1.

⁹ The density of MGO is 0,836 kg/l [14:19]. One tonne of MGO = $1000 \text{ kg} / 0,836 \frac{\text{kg}}{\text{l}} = 1196,2 \text{ liters}$

The average price in the year 2010 was 0,62 €/liter. In the year 2011 the average price had increased 18,4% from the previous year up to 0,76 €/liter. With the average price of 0,87 €/liter in the year 2012 the increase was about 13% from the year 2011. From January 2010 until December 2012 the MGO price increase at N1 was 35%, see Appendix 10.4.

For this feasibility study two price levels for MGO will be used. A "Central" price which will be the average price of MGO last year (2012) and a "High" price which is a 20% addition to the "Central" price based on past years growth rate from Figure 31. The estimated "Central" and "High" price of MGO to the ship owners in Iceland and used in this study is shown in Table V.

TABLE V.
MGO PRICES IN ICELAND

Price Level	MGO Price €/tonn
Central	1.043
High	1.252

Some fishing companies get discounts from their fuel oil providers but it is difficult to estimate what that discount might be and therefore it will not be taken into account in this study. It could also be assumed that an LNG fuel provider would also provide discount to their customers and therefore could all discounts be leveled out.

9.2 LNG price in Iceland

The cost of fuel consists of two main parts:

- The cost for the fuel at a major European import hub
- Infrastructure cost i.e. the storage cost and the transport cost between hubs and ports and to the end user [12:18].

The estimated LNG fuel price to the ship owners in Iceland is based on price estimations from the DMA-report. The price levels are "Low", "Central" and "High" estimations. Table VI shows the import price of LNG [12:19].

TABLE VI.
LNG IMPORT PRICE

Price Level	LNG import price €/tonn
Low	315
Central	440
High	570

The infrastructure costs of LNG were based on three model port cases: a large-scale, medium-scale and a small-scale terminal, for definition see Table III in chapter 7.5. The main characteristics of these three ports are in Appendix 3. The investment and operational cost of infrastructure for each port case are shown in Table VII [12:22].

TABLE VII.
INFRASTRUCTURE COST FOR THE PORT CASES

LNG Port Case	Large scale Port Case I	Medium scale Port Case II	Small scale Port Case III
Total initial investment cost (million €)	69	137	15
-therof investment in bunker vessels (million €)	32	60	-
Total operational cost (million €/yr)	10	17	3
-therof fixed operational cost of bunker vessels (million €/yr)	2	4	-
-therof fuel costs for bunker vessles (million €/yr)	0,5	1	-

The needed income for each port case dependent on the payback period is shown in Table VIII [12:22].

TABLE VIII.
DISTRIBUTION COSTS PER TONNE FOR THE PORT CASES

LNG Port Case	Large scale Port Case I	Medium scale Port Case II	Small scale Port Case III
Needed income to reach 8 years payback (€/tonne LNG)	136	157	211
Needed income to reach 10 years payback (€/tonne LNG)	118	137	194
Needed income to reach 12 years payback (€/tonne LNG)	107	125	183
Needed income to reach 15 years payback (€/tonne LNG)	95	112	172

This shows that the storage, transshipment and handling costs of LNG are very dependent on the payback period, the investment cost and the throughput of LNG per year. Longer payback periods give LNG a more competitive advantage. From this it is assumed that a infrastructure cost of 170 €/tonne is added on the LNG import prices in Table VI [12:22].

To correct for longer distances in transshipment to Iceland and the probability of higher investment cost for ports an estimated 11,5% is added to the infrastructure cost raising it to 190 €/tonne. In addition a carbon tax of 38,2 €/tonne¹⁰ is also added on the end-user price [76]. The estimated end-user price of LNG in Iceland for the three different price levels is shown in Table IX.

¹⁰ Carbon tax = 6.300 ISK/tonne ; EUR = 164,9 ISK ; $6.300/164,9 = 38,2$ €/tonne

TABLE IX.
LNG END-USER PRICE IN ICELAND

Price Level	LNG Price €/tonn
Low	543
Central	668
High	798

For this feasibility study it is assumed that an infrastructure for LNG exist in Iceland and the local ship owners can buy LNG at these prices.

9.3 HB Grandi hf.

One of the largest fishing companies in Iceland is HB Grandi. They consider themselves a leader in their field. HB Grandi places a great emphasis on using the latest advances in technology for fishing and processing of fish. Emphasis is placed on respecting natural resources and responsible fisheries. The company products are both ground fish and pelagic fish and are marketed worldwide. About 700 employees work for the company, both at sea and ashore [81]. HB-Grandi's fishing fleet consists of five freezer trawlers, three wetfish trawlers and four pelagic vessels [82]. LNG as a fuel for the freezer trawlers is not considered to be suitable because those ships are out at sea for one month at a time and the amount of LNG and the size of LNG tanks needed onboard to last a voyage would be very space consuming, taking up valuable cargo space. This study will cover all the wetfish trawlers and three pelagic vessels. One of the pelagic vessels is 52 years old with only 60 days per year out at sea¹¹ and will therefore not be included in the study.

In the following chapters information and calculations of one wetfish trawler will be explained in detail. The calculations of the other ships are presented in appendixes.

¹¹ Information received 15.02.2013, from Loftur B. Gíslason Production manager at HB-Grandi.

9.4 Wetfish trawler switching to dual-fuel LNG propulsion



Figure 32. Sturlaugur H. Böðvarsson [83]

Sturlaugur H. Böðvarsson AK-10, is a steel structured wetfish trawler, built in Iceland by Þorgeir & Ellert hf. at Akranes in the year 1981. The length of the ship is 44.2 m, beam is 9.00 m and the depth is 6.4 m. The ships gross tonnage (GT) is 712 [84:101].

The main engine was produced by Werkspoor from the year 1986, with 1470 kW power. The ship has two Caterpillar 3412 TA with two Stamford generators, 246 kW at 1500/rot/min. The main engine has a Stamford MSC 534E generator, 335 kW at 1500/rot/min. The fishing gear used is mainly bottom trawl but during a few voyages over the year pelagic trawl is used. Table X shows the total numbers of days out at sea and the average number and length of voyages last year, 2012¹².

TABLE X.
LAST YEAR VOYAGES AND SEA TIME

	Days at sea/year	Average length of voyage	Voyage/year
Sturlaugur H. Böðvarsson	301	5,4	56
Bottom trawl	295	5,6	53
Pelagic trawl	6	2,0	3,0

To ensure that sufficient energy supply is calculated for a voyage a 20% margin is added to the average voyage length from Table X, making it 6,48 days. With 301 days per year at sea the number of voyages each year would be 46,5.

¹² Information received 15.02.2013, from Loftur B. Gíslason Production manager at HB-Grandi.

The total amount of fuel the ship consumed last year was 1.482.041 liters of MGO¹³, converted to tonnes:

$$(1.482.041l * 0,836 \text{ kg/l}) / (1000 \text{ kg / tonne}) = 1.239 \text{ tonnes}^{14}$$

The amount of oil needed per voyage was:

$$1.482.041 \text{ liters} / 46,5 \text{ voyages} = 31.872 \text{ liters}$$

General information and last year oil consumption of the other ships are in Appendix 4.

9.4.1 Energy demand running on dual-fuel LNG

If this particular ship would be converted or a similar ship would be built with dual-fuel propulsion running on LNG as the main fuel source and MGO as a backup fuel an estimation has to be made on the amount of LNG and MGO needed per voyage, the size of LNG tanks and the additional space required onboard the ship. This estimation will be based on the ships MGO consumption last year, 2012.

Dual-fuel engine characteristics

Dual-fuel engines in gas mode do not operate efficiently at engine loads higher than 80% as well as at engine loads lower than 15% and need to switch to diesel-mode during that time [13:12]. It is estimated that the wetfish trawlers could operate at engine loads below 80% for about 75% of the voyage using LNG as a fuel. At high engine load periods, during 25% of the voyage, the ship would need to use MGO as a fuel. For the pelagic vessels it is estimated that they could operate at engine loads below 80% for about 90% of the voyage resulting in a high engine load period of only 10% of the voyage, see Appendix 10.1 . The ships are almost never operating at engine loads below 15%, only while the engine is turned on and off and the MGO demand during this time is extremely small, see Appendix 10.2. It will therefore not be accounted for in this study.

In addition to the MGO needed at high engine loads a small amount of MGO is needed to ignite the LNG for combustion, less than 1% of the total fuel demand [14:21].

¹³ Information received 15.02.2013, from Loftur B. Gíslason Production manager at HB-Grandi.

¹⁴ The density of MGO is 0,836 kg per liter [14:19].

MGO needed at high engine loads

The total installed power of this ship (Sturlaugur), main power and auxiliary power, is 1962 kW. During high engine load periods the ship would need to use 80-100% of that total power, or 1570-1962 kW. It is assumed that on average 90% of the total power, or 1765 kW, would be used for high load periods. If one voyage is about 6,48 days equal to 155,5 hours at sea, 25% of that time at high engine loads is about 39 hours. The output power needed from the engine at high load duration is then:

$$1765 \text{ kW} * 39 \text{ h} = 68.835 \text{ kWh}$$

Because the efficiency of a diesel engine is only 45-50% [15:6] much more input energy in the form of oil is required. The total energy the engine needs, assuming 45% efficiency, is:

$$68.835 \text{ kWh} / 0,45 = 152.967 \text{ kWh}$$

The energy in one kg of MGO is 11,9 kWh¹⁵. The amount of MGO needed at high load period is:

$$152.967 \text{ kWh} / 11,9 \text{ kWh/kg} = 12.854,4 \text{ kg}$$

The density of one liter of MGO is 0,836 kg [14:19]. The volume of this amount of MGO is:

$$12.854,4 \text{ kg} / 0,836 \text{ kg/l} = 15.376 \text{ liters}$$

MGO needed as ignition source for LNG

The total amount of oil needed per voyage while running only on MGO was 31.872 liters and the amount still needed for high load periods after switching to dual-fuel LNG propulsion is 15.376 liters. The amount of MGO remaining is:

$$31.872 \text{ liters} - 15.376 \text{ liters} = 16.496 \text{ liters}$$

One percent of this amount will be needed as an ignition source for the LNG equal to 165 liters of MGO.

¹⁵ MGO energy = 42,6 MJ/kg [16]; MJ= 0,28 kWh; MGO energy = 42,6 * 0,28 = 11,9 kWh/kg

The total amount of MGO needed

The calculations above show that the MGO still needed per voyage after switching to dual-fuel LNG propulsion would be:

$$15.376 \text{ liters (for high loads)} + 165 \text{ liters (as ignition fuel)} = 15.541 \text{ liters}$$

This means that about 49% of the MGO used per voyage last year is still needed after a switch to dual-fuel LNG propulsion. With 46,5 voyages per year the total MGO needed per year would be:

$$15.541 \text{ liters} * 46,5 \text{ voyages} = 722.657 \text{ liters}$$

Converted to tonnes:

$$(722.657 \text{ liters} * 0,836 \text{ kg/l}) / (1000 \text{ kg / tonne}) = 604,1 \text{ tonnes}$$

The amount of LNG needed

Once the MGO still needed per voyage after a switch to dual-fuel LNG has been subtracted from the total MGO needed per voyage before (last year), the remaining MGO is then converted to LNG. The MGO remaining is:

$$31.872 \text{ liters (before)} - 15.541 \text{ liters (after)} = 16.331 \text{ liters}$$

This amount of MGO is then converted to LNG by multiplying with the factor of 1,6 to get the same amount of energy as the MGO (explained in chapter 7.7.2):

$$16.331 \text{ liters} * 1,6 = 26.130 \text{ liters of LNG per voyage}$$

The amount of LNG needed per year would be:

$$26.130 \text{ liters/voyage} * 46,5 \text{ voyages} = 1.215.045 \text{ liters}$$

Converted to tonnes:

$$(1.215.045 \text{ liters} * 0,44 \text{ kg/l}) / (1000 \text{ kg / tonne}) = 534,6 \text{ tonnes}^{16}$$

¹⁶ The density of LNG is 0,440 kg per liter [14:19]

9.4.2 Tank size and space needed

For 26.130 liters of LNG needed per voyage the bunkering volume in cubic meters would be:

$$26.130 \text{ liters} / 1000 \text{ l/m}^3 = 26,1 \text{ m}^3$$

If one LNG tank would be placed onboard the ship with a filling ratio of 90% the tank's inside volume would be:

$$26,1 \text{ m}^3 / 0,90 = 29 \text{ m}^3$$

The current tank space onboard the ship is 110.000 liters equal to 110 m³, see Appendix 10.8. Some of this tank space is used for balancing the ship. The fuel space demand while running only on MGO is 31.872 liters or about 32 m³ per voyage. After a switch to dual-fuel LNG propulsion, 16.331 liters of MGO equal to 16,3 m³ is converted to LNG. About 2,5-4,0 times more space is required for the LNG tank compared to the MGO tanks [14:8]. The maximum space demand onboard the ship for the LNG tank would be:

$$16,3 \text{ m}^3 * 4,0 = 65,2 \text{ m}^3$$

At least 15.541 liters of MGO is still needed for one voyage consuming 15,5 m³ of space. The total space needed onboard for both the LNG and MGO after a switch would be:

$$15,5 \text{ m}^3 (\text{for MGO}) + 65,2 \text{ m}^3 (\text{for LNG}) = 80,7 \text{ m}^3$$

The additional space demand after a switch to dual-fuel LNG propulsion would therefore be:

$$80,7 \text{ m}^3 (\text{after}) - 32 \text{ m}^3 (\text{before}) = 48,7 \text{ m}^3$$

Figure 33 shows a comparison of the space demand needed.

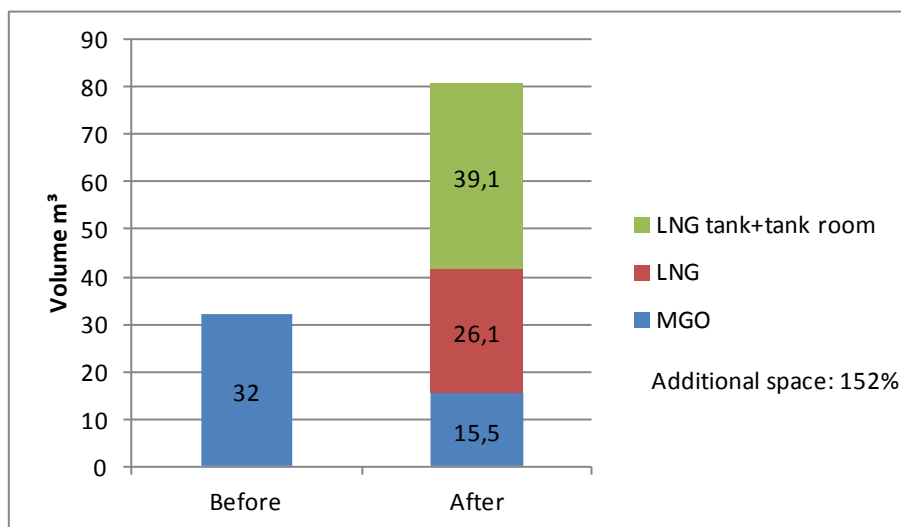


Figure 33. Comparison of space demand

Calculations of the total MGO and LNG demand for the other ships after a switch to dual-fuel LNG propulsion as well as the tank size and space demand are in Appendix 5.

9.4.3 Investment and operational cost

The investment cost is the amount of money required for a project, as converting an fishing ship to be able to run on dual-fuel LNG propulsion or buying a new ship. The fishing ship owner would not invest unless he is certain that the investment can be paid up with the projects profit (operational savings) over an acceptable time with reasonable discount rate. In this chapter the investment cost of a conversion and the added cost imposed on a new ship with dual-fuel LNG propulsion is estimated and the expected operational savings gained is calculated.

Conversion to Dual-fuel engine for LNG propulsion

According to the engine manufacturing company Wärtsilä the cost of converting an engine to dual-fuel LNG propulsion is in the region of 1-1,5 million EUR depending on where and how the conversion is done. Once the cost of the LNG system, tanks, piping and all yard work has been added to the price the estimated total cost could be about 5-7 million EUR, see Appendix 10.5.

For this study the conversion cost of the pelagic vessels will be based on the higher estimation of 7 million EUR and the wetfish trawlers will be based on the lower estimation of 5 million EUR. The reason for this is that compared to the wetfish trawlers the pelagic vessels are larger ships, have more installed power, consume more fuel per voyage and need a larger LNG system.

Added investment cost of a new ship

If a new ship would be built running on dual-fuel LNG propulsion the added investment cost could be about 10-20% more than for a conventional oil fuelled ship. The main reason for this additional cost are the expensive LNG storage tanks, the fuel piping system and in some cases the ships need to be built a bit larger [3:10]. According to DNV the main factors that influence the cost of a LNG system are the ship type, size and the tank volume needed. The engine cost can be about 20% more expensive than for a conventional engine. The total added investment for LNG propulsion including the engine, tank and the balance of the plant cost is based on the ships installed power, see Figure 34 [19:11].

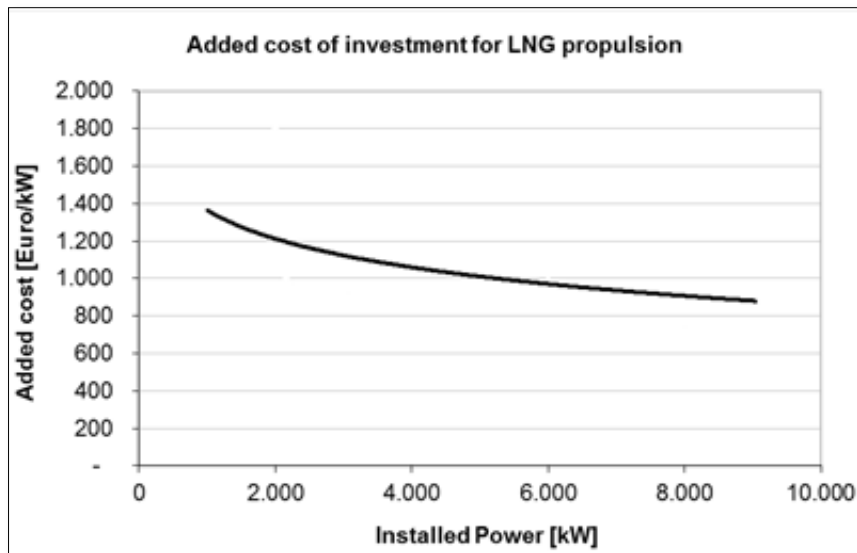


Figure 34. Added cost of investment for LNG propulsion

For the trawler Sturlaugur, that has a total installed power of 2.297 kW, the added cost would be about 1100 €/kW. The added cost of investment for a new ship with LNG propulsion would be:

$$1.962kW * 1200 \text{ €/kW} = 2.354.400 \text{ €}$$

To verify if this complies with the estimation that the added cost could be about 10-20% more than for a conventional oil fuelled ship an engineering services company for ships in Iceland, NAVIS ehf., was contacted for a price estimation of a wetfish trawler and a pelagic vessel. According to NAVIS the cost depends highly on where in the world the ships are built. The price depends also on the equipment needed, ships with refrigeration capacity like the pelagic vessels are more expensive. It is estimated that a wetfish trawler with a length of 50 m, beam of 12 m and a depth of 7,6 m would cost about 15,2-16,4 million EUR delivered at the shipyard. The estimated cost of a pelagic vessel, with a length of 67 m, beam of 15 m and a depth of 8,5m, is about 27,3-31,5 million EUR. These numbers are based on contract prices to fishing companies in Western Europe for new built ships that have been delivered this year 2013 and last year. The cost of the fishing gear is not included in these prices, see Appendix 10.6.

Because this ship, Sturlaugur is a bit smaller ship than the trawler in the estimation the lower price estimation of 15,2 million EUR will be used. The added investment cost in percentages is then:

$$2.354.400 \text{ € (added investment cost)} / 15.200.000 \text{ €} = 0,155 * 100 = 15,5\%$$

This is within the estimated added investment cost of 10-20% that indicates that these calculations can be reliable. The added investment cost of the other ships is in Appendix 6.

Operational costs

The cost of maintenance for this particular ship last year was 225.950 EUR ¹⁷. It is assumed that the maintenance of a dual-fuelled ship would cost 5% more, because it includes two systems to maintain. The additional annual maintenance cost of the ship would be 11.297 EUR.

Last year the ship consumed 1.239 tonnes of MGO. The cost of this amount of fuel, based on MGO prices from table V, is shown in table XI.

TABLE XI.
COST OF MGO LAST YEAR 2012

Price level	Price €/tonne	Cost/year
MGO Central	1.043 €	1.292.263 €
MGO High	1.252 €	1.551.211 €

After a switch to dual-fuel LNG propulsion the ship would still need 604,1 tonnes of MGO per year as calculated in chapter 9.4.1. The cost of this amount of fuel is shown in table XII.

TABLE XII.
ANNUAL COST OF MGO AFTER A
SWITCH TO DUAL-FUEL LNG PROPULSION

Price level	Price €/tonne	Cost/year
MGO Central	1.043 €	630.076 €
MGO High	1.252 €	756.333 €

The amount of LNG needed per year would be 534,6 tonnes. The cost of this amount of fuel, based on LNG prices from table IX, is shown in table XIII.

TABLE XIII.
ANNUAL COST OF LNG AFTER A
SWITCH TO DUAL-FUEL LNG PROPULSION

Price level	Price €/tonne	Cost/year
LNG Low	543 €	290.288 €
LNG Central	668 €	357.113 €
LNG High	793 €	423.938 €

From the estimated fuel prices of MGO and LNG in Iceland, six price scenarios will be used in this study, based on example in the DMA-report, see table XIV.

¹⁷ Information received on 15.02.2013, from Loftur B. Gíslason Production manager at HB-Grandi.

TABLE XIV.
SIX PRICE SCENARIOS OF FUEL COST [12:23]

Scenario name	MGO price level	MGO price	LNG price level	LNG price
1. Low LNG/Central MGO	Central	1.043 €	Low	543 €
2. Central LNG/Central MGO	Central	1.043 €	Central	668 €
3. High LNG/Central MGO	Central	1.043 €	High	798 €
4. Low LNG/High MGO	High	1.252 €	Low	543 €
5. Central LNG/High MGO	High	1.252 €	Central	668 €
6. High LNG/High MGO	High	1.252 €	High	798 €

From these six price scenarios the annual fuel cost for Sturlaugur after a switch to dual-fuel LNG propulsion would be according to table XV.

TABLE XV.
ANNUAL FUEL COST AFTER A SWITCH TO DUAL-FUEL LNG PROPULSION

Scenario name	LNG cost/year	MGO cost/year	Total cost/year
1. Low LNG/Central MGO	290 €	630 €	920 €
2. Central LNG/Central MGO	357 €	630 €	987 €
3. High LNG/Central MGO	424 €	630 €	1.054 €
4. Low LNG/High MGO	290 €	756 €	1.047 €
5. Central LNG/High MGO	357 €	756 €	1.113 €
6. High LNG/High MGO	424 €	756 €	1.180 €

Note: the cost is expressed in thousand Euros

The annual fuel savings after a switch to dual-fuel LNG propulsion and the annual operational savings gained once the added cost for maintenance has been subtracted from the fuel savings is shown in Table XVI.

TABLE XVI.
ANNUAL OPERATIONAL SAVINGS AFTER A SWITCH TO DUAL-FUEL LNG PROPULSION

Scenario name	Before:	After:			
	MGO Only	Dual-fuel	Fuel Savings	Added cost for maint.	Total operational savings
1.	1.292 €	920 €	372 €	11,3 €	361 €
2.	1.292 €	987 €	305 €	11,3 €	294 €
3.	1.292 €	1.054 €	238 €	11,3 €	227 €
4.	1.551 €	1.047 €	505 €	11,3 €	493 €
5.	1.551 €	1.113 €	438 €	11,3 €	426 €
6.	1.551 €	1.180 €	371 €	11,3 €	360 €

Note: the cost is expressed in thousand Euros

The total operational savings that could be attained each year is 18-32% by switching to dual-fuel LNG propulsion depending on the six fuel price scenarios and the estimated fuel prices. The operational cost calculations of the other ships are in Appendix 7.

9.5 NPV calculation

To assess if it would be economically feasible for the ship owners, to either convert existing ship to run on dual-fuel LNG propulsion or to add to the investment cost of a new ship, the net present value (NPV) method is used, see formula below:

$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \dots + \frac{C_T}{(1+r)^T}$$

$- C_0 = \text{Initial Investment}$
 $C = \text{Cash Flow}$
 $r = \text{Discount Rate}$
 $T = \text{Time}$

Equation 1. Net Present Value formula [85]

This is a formula that determines the present value of the investment by the saved operating cost (cash flow) received each year from the project. These assumptions were used in the NPV calculations of the ships in this study:

- Discount Rate (r): 10%¹⁸.
- No inflation and all prices are fixed prices.
- Economic life time (T)¹⁹: 20 years

The NPV is calculated from the estimated investment cost of a conversion and the added investment cost imposed on a new built ship and the annual operational savings gained depending on the six price scenarios. If at the end of the economic life time of 20 years the NPV is positive the investment adds value for the ship owner and the investment would be considered economically feasible. The NPV calculations of all the ships are in Appendix 8.

¹⁸ According to Rúnar Þór Stefánsson the Fishery Manager at HB Grandi it is natural to assume a minimum of 10 % discount rate, see e-mail in Appendix 10.7.

¹⁹ Expected useful life of an asset, usually less than the assets physical life [86].

9.6 Emission reduction

To evaluate the environmental gain for the ships to switch to dual-fuel LNG propulsion an emission reduction has been calculated using the emission comparison Table XVII.

TABLE XVII.
EMISSION COMPARISON OF MGO AND LNG [20:2]

Fuel type	SO _x (g/kWh)	NO _x (g/kWh)	PM (g/kWh)	CO ₂ (g/kWh)
MGO 0,1% sulphur	0,4	8-11	0,15-0,25	580-630
LNG	0	2	0,07	430-480

The wetfish trawler Sturlaugur consumed 1.239 tonnes of MGO last year. One kg of MGO contains about 11,9 kWh of energy [16]. The total amount of energy in the fuel consumed last year was:

$$1.239.000 \text{ kg} * 11,9 \text{ kWh/kg} = 14.744.100 \text{ kWh}$$

If this ship would run on dual-fuel LNG propulsion the MGO still needed for high engine loads and as injection fuel for the LNG would be 604,1 tonnes per year. The energy in this amount of MGO is:

$$604.100 \text{ kg} * 11,9 \text{ kWh/kg} = 7.188.790 \text{ kWh}$$

The LNG demand would be 534,6 tonnes per year. One kg of LNG contains about 13,5 kWh of energy [16]. The total energy in this amount of LNG is:

$$534.600 \text{ kg} * 13,5 \text{ kWh/kg} = 7.217.100 \text{ kWh}$$

The total annual emissions expressed in tonnes before and after a switch to dual-fuel LNG propulsion and the annual reduction gained is shown in Table XVIII.

TABLE XVIII.
ANNUAL EMISSION REDUCTION WITH A SWITCH TO DUAL-FUEL LNG PROPULSION

	Fuel	SO _x	NO _x	PM	CO ₂
Before:	MGO	5,9	140	2,9	8.920
After:	MGO	2,9	68	1,4	4.349
	LNG	0,0	14	0,5	3.284
	Total: MGO+LNG	2,9	83	1,9	7.633
Reduction:		3,0	57	1,0	1.287

The emission reduction for Sturlaugur is visualized in the following figures for better understanding.

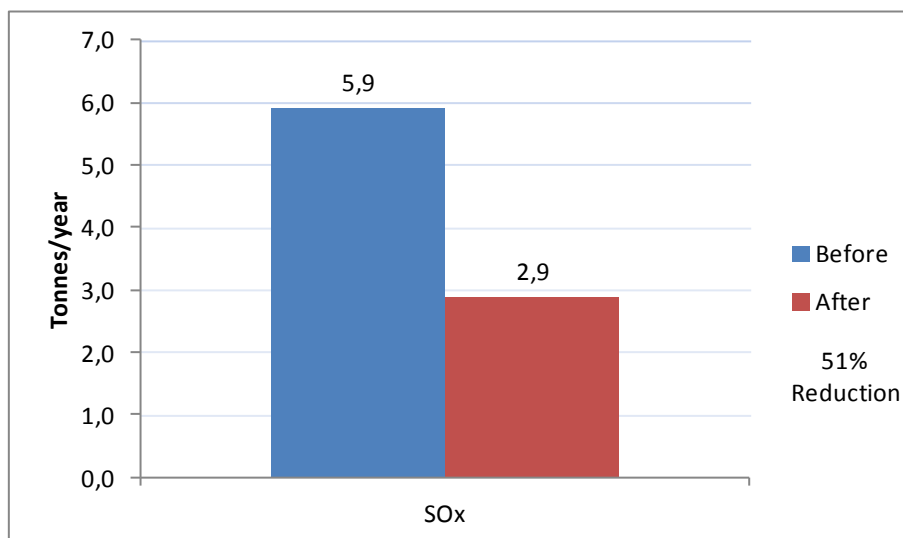


Figure 35. SO_x reduction with a switch to dual-fuel LNG propulsion

The sulphur emission has the highest reduction of 51% because LNG as a fuel contains no sulphur. The sulphur emission comes purely from the MGO still needed.

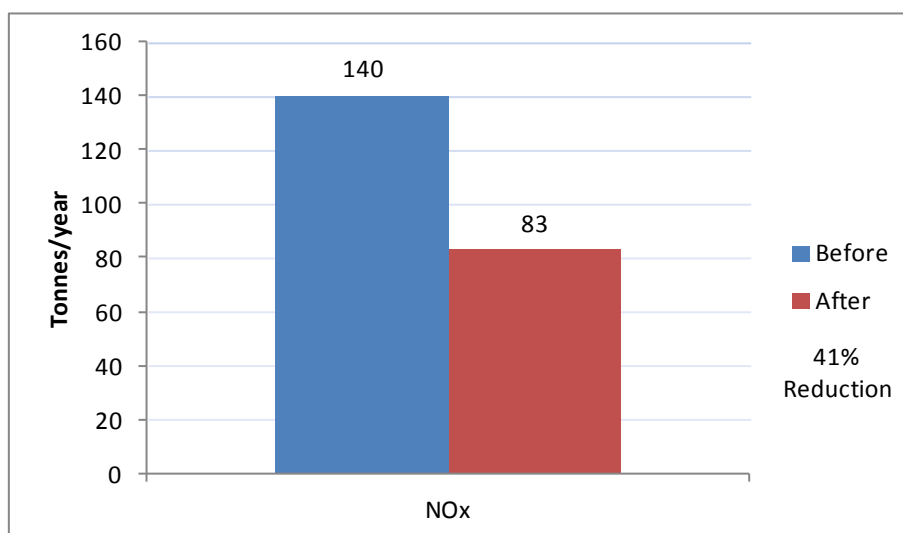


Figure 36. NO_x reduction with a switch to dual-fuel LNG propulsion

Nitrogen oxide (NO_x) emission is reduced by 41% and very little comes from the LNG as table XVII shows.

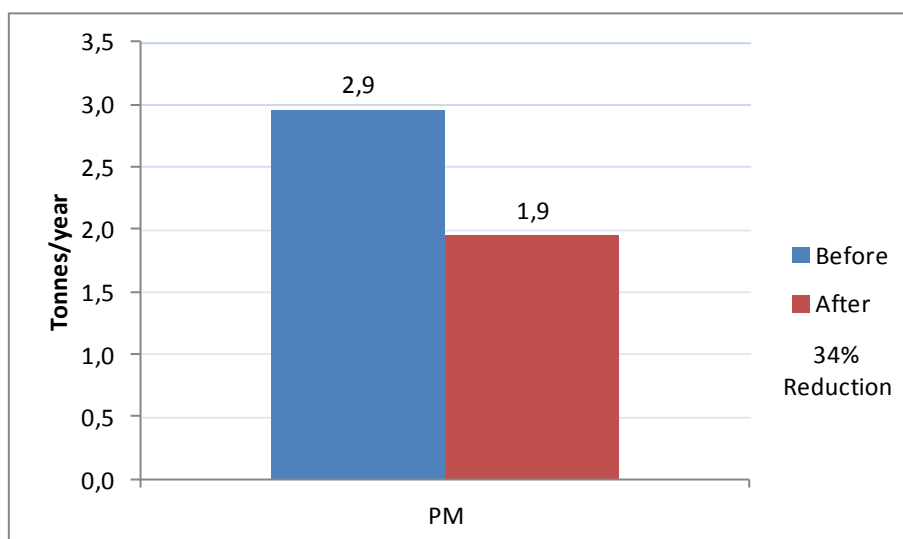


Figure 37. PM reduction with a switch to dual-fuel LNG propulsion

The particulate matter (PM) emission is reduced by 34% and very little comes from the LNG as table XVII shows.

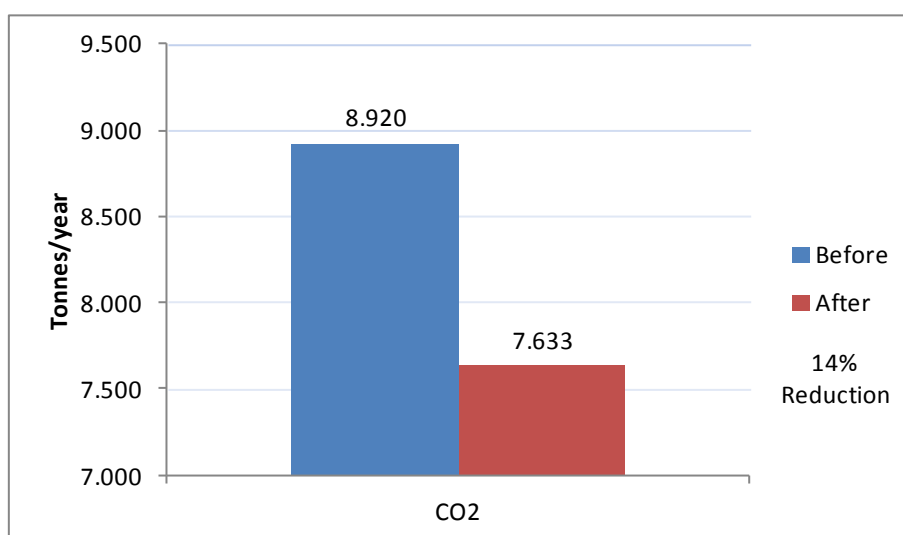


Figure 38. CO₂ reduction with a switch to dual-fuel LNG propulsion

The carbon dioxide (CO₂) emission is reduced by 14% and is that the lowest reduction gained of the four pollutants. The reason for this low reduction is that LNG is a fossil fuel and contains carbon but about 20-25% less than MGO and because some MGO is still needed after a switch to dual-fuel LNG propulsion a higher reduction is not attained. The emission reduction of the other ships are in Appendix 9.

10. Results

Of the total amount of MGO the ships consumed last year some would still be needed after a switch to dual-fuel LNG propulsion. The wetfish trawlers needed more proportion of MGO after the switch than the pelagic vessels. The wetfish trawler Sturlaugur needed 49% of the MGO consumed last year, Ásbjörn 50% and Ottó 51%. The pelagic vessel Ingunn needed 25% of the MGO consumed last year, Faxi 28% and Lundey 30%. The less proportion that the ships needed of the MGO consumed last year, more LNG as a fuel could be used.

Because LNG is more space consuming than the MGO, the maximum additional space required onboard the ships after a switch to dual-fuel LNG propulsion was more where higher proportion of LNG compared to MGO was needed per voyage.

The maximum additional space required for the wetfish trawlers was 147% for Ottó, 150% for Ásbjörn and 152% for Sturlaugur. Much greater additional space was required for the pelagic vessels, Ingunn required 221% additional space, Faxi 214% and Lundey 212%.

10.1 Economical

The added investment cost imposed on a new pelagic trawler was almost double the added investment cost of a new wetfish trawler. The difference in the cost of a conversion for the two ship types was not as high but the cost was lower for the wetfish trawlers.

The study showed that annual operational savings would be gained for all the ships by switching to dual-fuel LNG propulsion. The total operational savings was dependent on the proportion of LNG and MGO needed after a switch as well as the price for LNG and MGO according to the six price scenarios used in this study. The greatest operational savings was gained from price scenario four (Low LNG/ High MGO), followed by price scenario five (Central LNG/High MGO), then price scenario one (Low LNG/Central MGO), price scenario six (High LNG/High MGO), price scenario two (Central LNG/Central MGO) and the lowest operational savings was gained from price scenario three (High LNG/Central MGO).

The NPV calculations showed that it would be feasible for the wetfish trawlers to add to the investment of a new trawler according to some price scenarios.

For Sturlaugur the NPV was positive at all price scenario except number three, see figure 39.

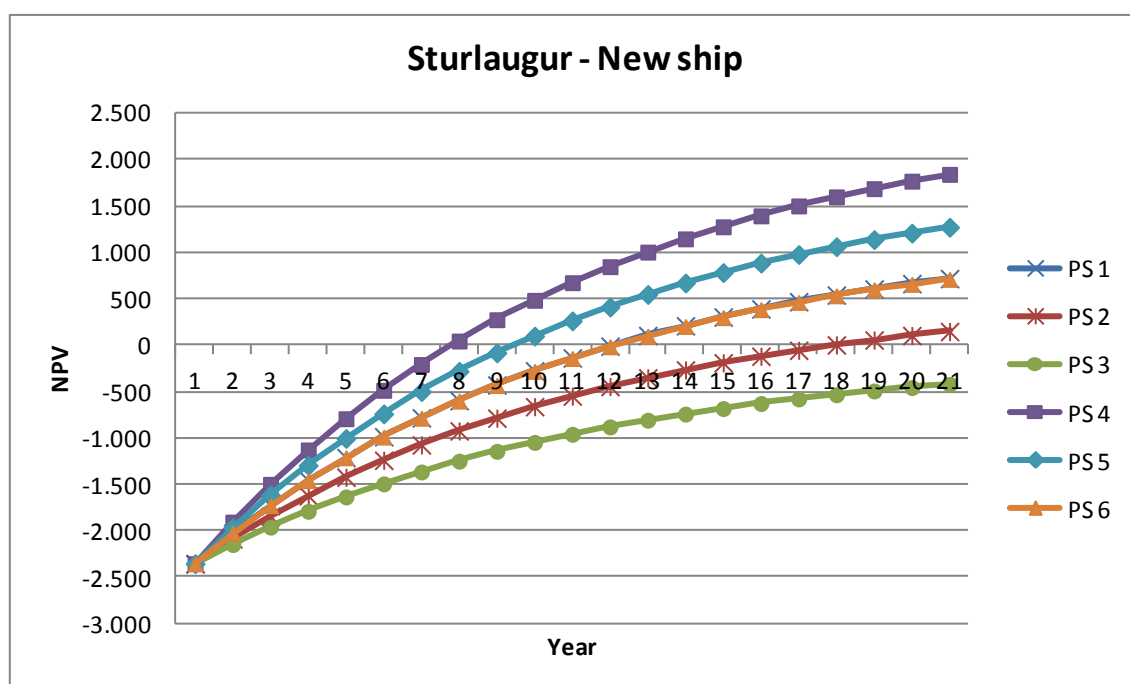


Figure 39. NPV for the added investment cost of a new ship - Sturlaugur

The shortest payback period for Sturlaugur was 7 years according to price scenario four, 9 years for price scenario five, 12 years for price scenario one and six and the longest payback period was 17 years for price scenario two.

For Ásbjörn the NPV was positive at all price scenario except number three, see figure 40.



Figure 40. NPV for the added investment cost of a new ship - Ásbjörn

The payback period for Ásbjörn was 8 years according to price scenario four, 10 years for price scenario five, 13 years for price scenario one and six and 20 years for price scenario two.

For Ottó the NPV was positive at price scenario number one, four, five and six, see figure 41.

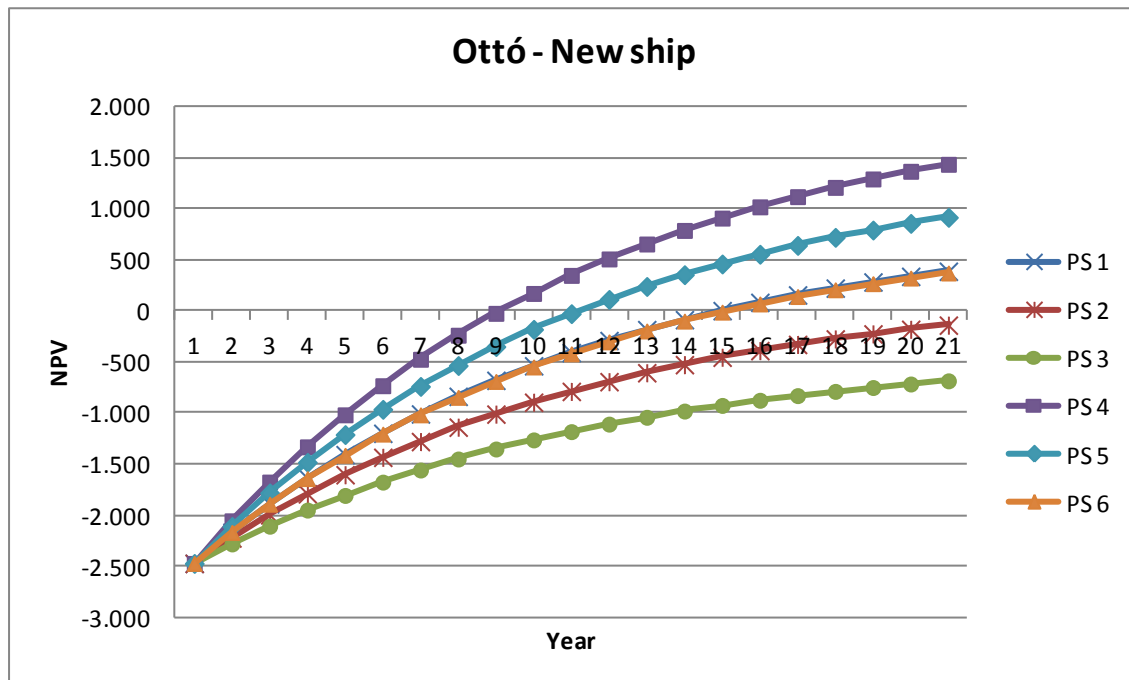


Figure 41. NPV for the added investment cost of a new ship - Ottó

The shortest payback period for Ottó was 9 years according to price scenario four, 11 years for price scenario five, 14 years for price scenario one and 15 years for price scenario six.

All the wetfish trawlers had a negative NPV for the investment of a conversion for all price scenarios.

The pelagic vessels showed feasibility both for the added investment cost of a new ships and for a conversion of existing ships.

The pelagic vessel Ingunn had a positive NPV of the added investment cost of a new ship according to all price scenarios except number three. The shortest payback period for Ingunn was 8 years according to price scenario four, 9 years for price scenario five, 12 years for price scenario one and six and the longest payback period was 18 years for price scenario two, see figure 42.

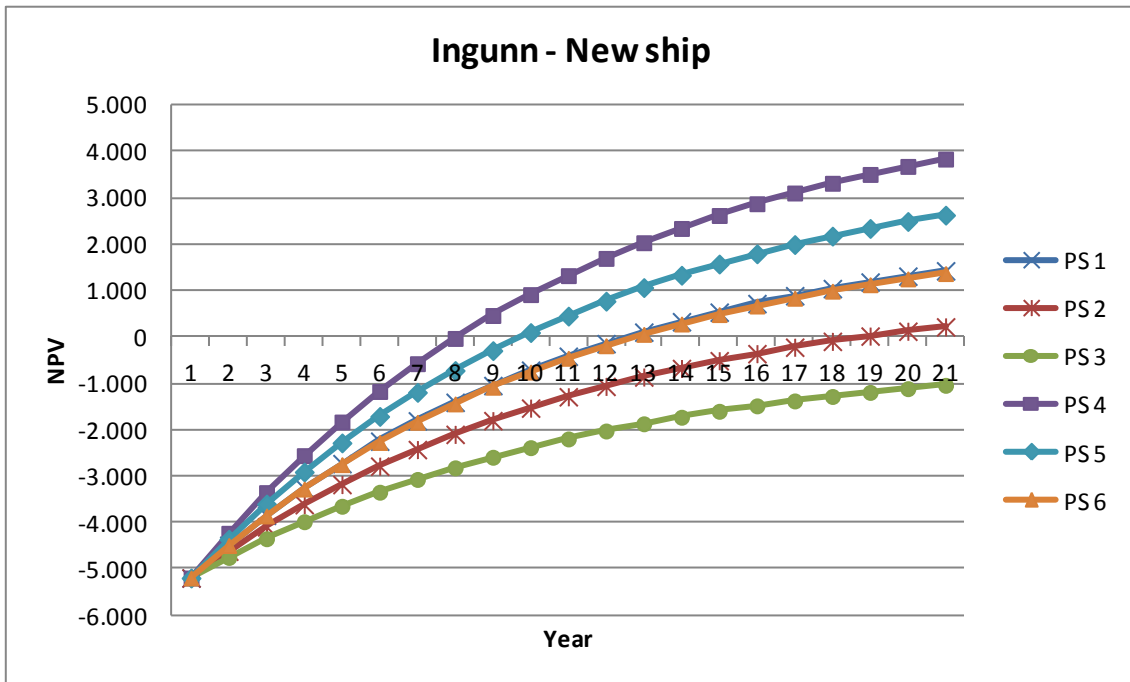


Figure 42. NPV for the added investment cost of a new ship - Ingunn

It would be feasible to convert the pelagic vessel Ingunn to dual-fuel LNG propulsion according to price scenario four and five, see figure 43.

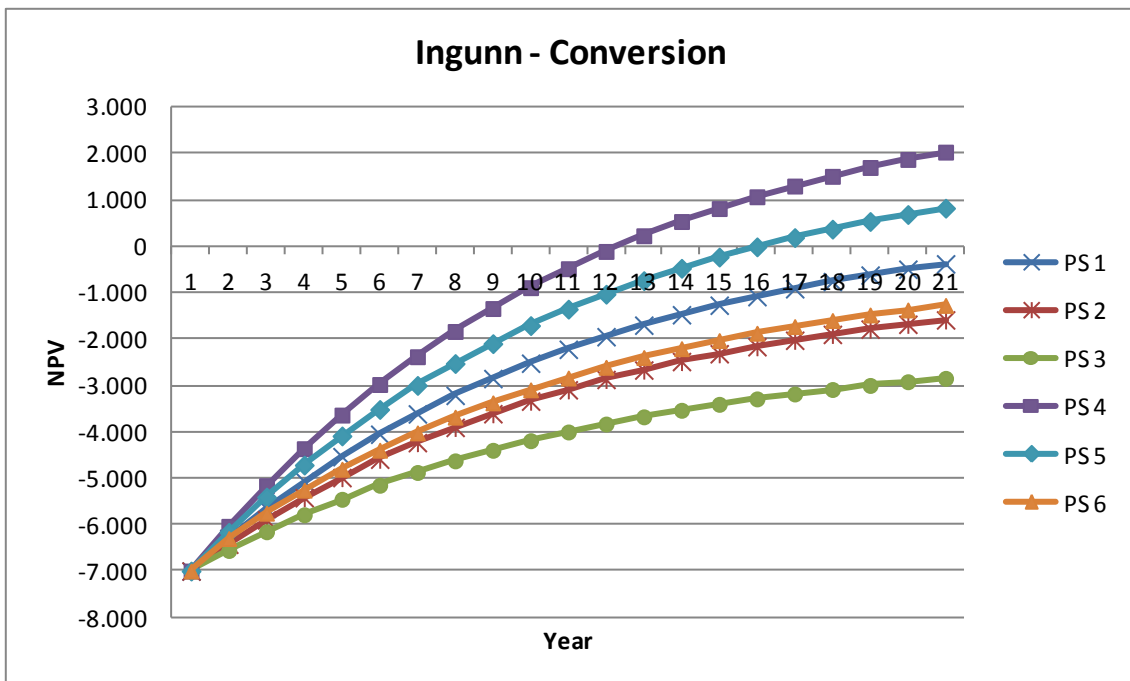


Figure 43. NPV for the investment of a conversion - Ingunn

The payback period would be 12 years according to price scenario four and 16 years for price scenario five.

For Faxi the NPV was positive for the added investment cost of a new ship according to price scenario one, four, five and six. The shortest payback period would be 10 years according to price scenario four, 13 years for price scenario five, 18 years for price scenario one and the longest payback period would be 19 years for price scenario six, see figure 44.

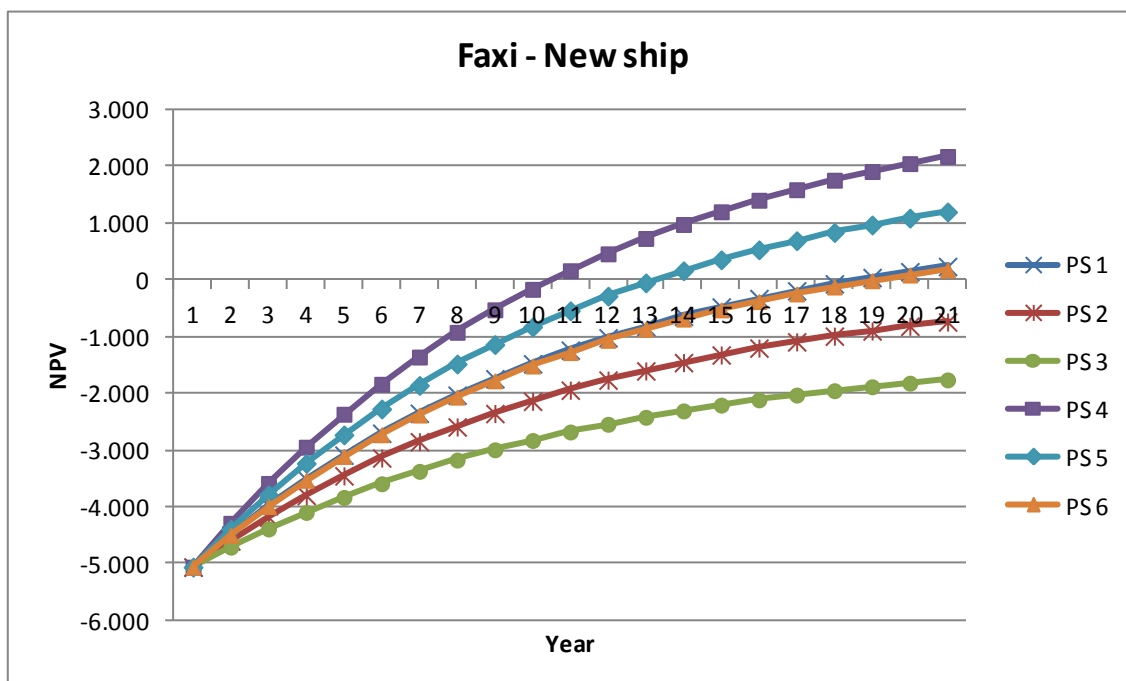


Figure 44. NPV for the added investment cost of a new ship - Faxi

It would only be feasible to convert the pelagic vessel Faxi according to price scenario four with a payback period of 19 years, see figure 45.

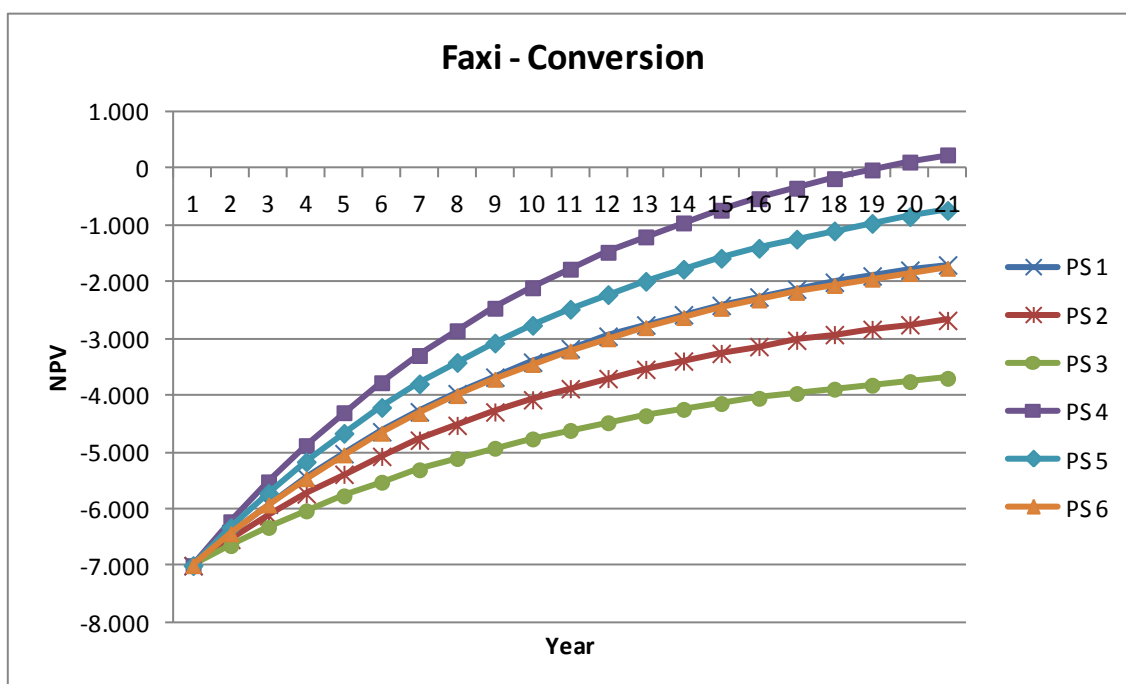


Figure 45. NPV for the investment of a conversion - Faxi

For Lundey the NPV was positive for the added investment cost of a new ship according to price scenario one, four, five and six. The shortest payback period would be 9 years according to price scenario four, 12 years for price scenario five, 16 years for price scenario one and the longest payback period would be 17 years for price scenario six, see figure 46.

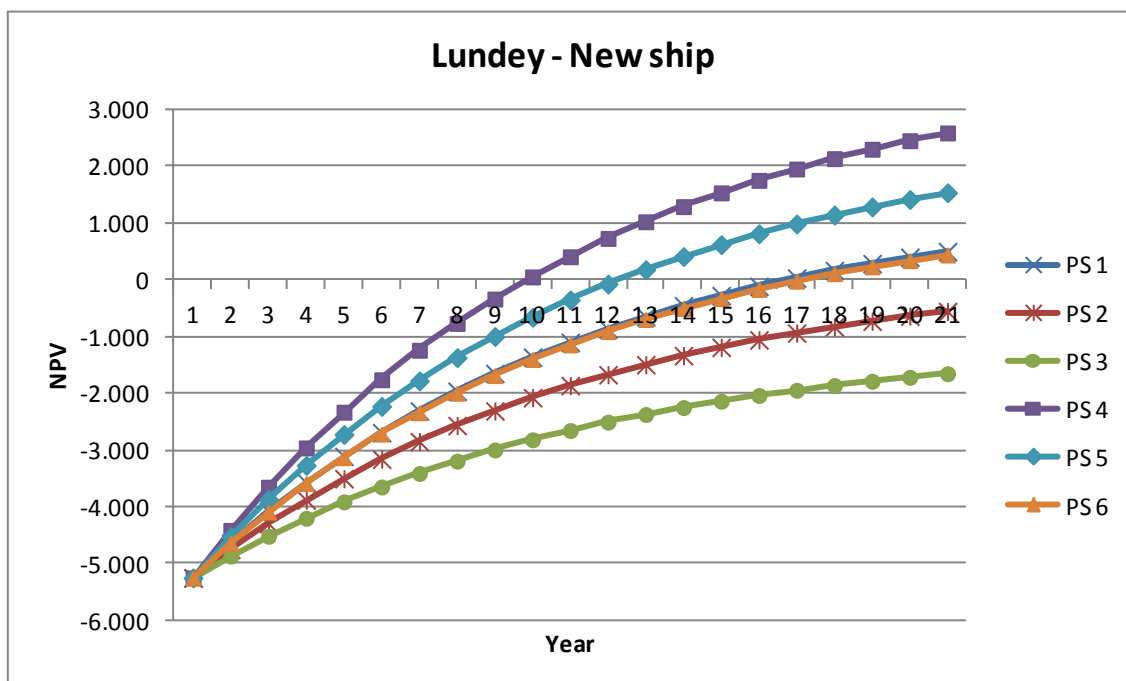


Figure 46. NPV for the added investment cost of a new ship - Lundey

It would only be feasible to convert the pelagic vessel Lundey according to price scenario four with a payback period of 15 years, see figure 47.

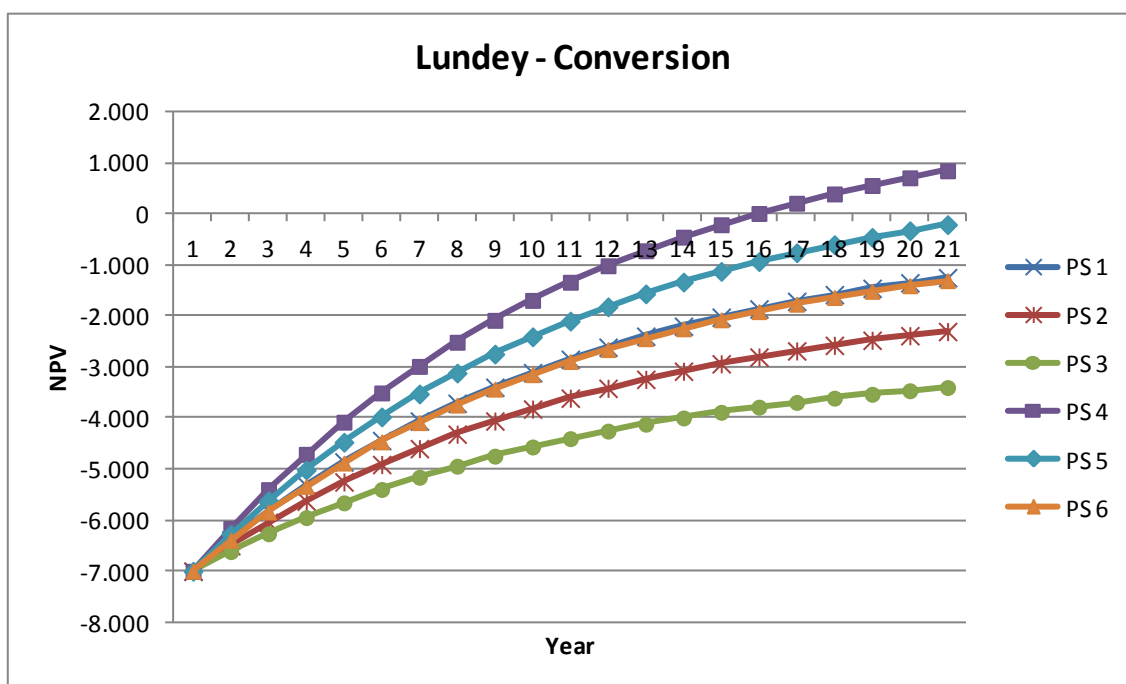


Figure 47. NPV for the investment of a conversion - Lundey

To demonstrate how the NPV results are sensitive to various discount rates, NPV calculations for the added investment cost of a new ship such as Sturlaugur with discount rates from 6-14% was conducted, see figure 48.

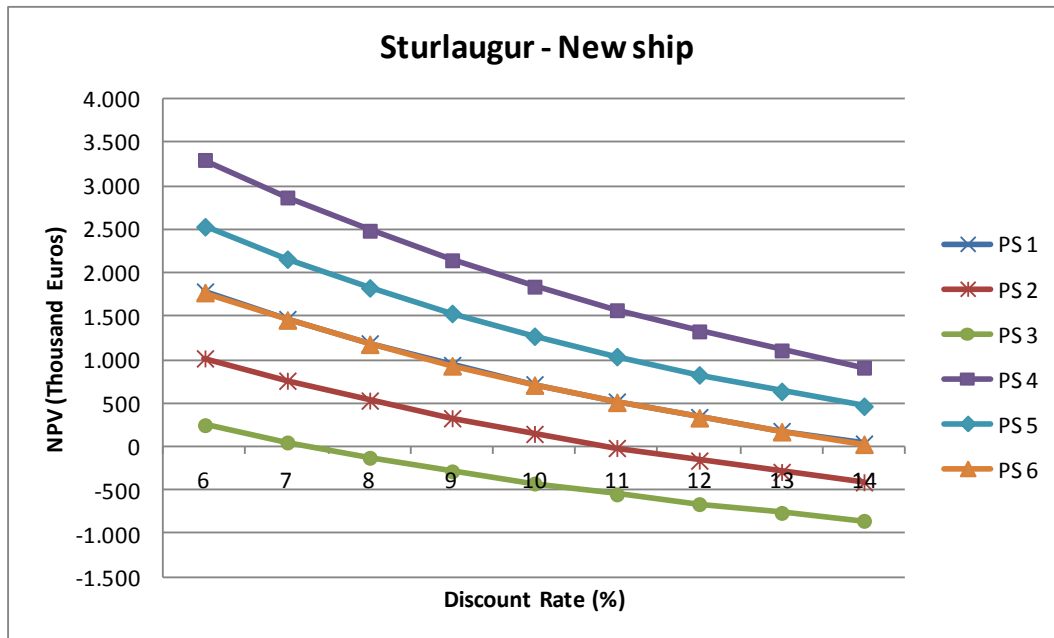


Figure 48. Various discount rates for the added investment cost of a new ship - Sturlaugur

The figure shows that by lowering the discount rate down to 6-7% the NPV would be positive at the end of 20 years for all price scenarios. As the discount rate increases the NPV decreases.

10.2 Environmental

By switching to dual-fuel LNG propulsion significant emission reduction of environmental pollutants were achieved. Of the four pollutions SO_x , NO_x , PM and CO_2 evaluated in this study the greatest reduction was achieved in SO_x emission followed by NO_x , then PM and the lowest reduction was achieved in CO_2 emission.

The greatest annual emission reduction of pollutions from the wetfish trawlers was achieved by Sturlaugur, the other two having about the same reduction from all four pollutions, slightly lower than Sturlaugur's. The emission reductions were much greater for the pelagic vessels than the wetfish trawlers. The greatest emission reduction from the pelagic vessels was achieved by Ingunn followed by Faxi and the lowest emission reduction was from Lundey.

The total annual emission reductions of all the ships combined were significant as Table XIX shows.

TABLE XIX.
EMISSION IN TONNES FROM ALL THE SHIPS COMBINED

	Fuel	SOx	NOx	PM	CO₂
Before	MGO	40,6	963	20,3	61.338
After	Total: MGO+LNG	15,3	485	11,9	50.412
	Reduction:	62%	50%	41%	18%

To put this in to context the entire Icelandic fishing fleet emitted 535 thousand tons of CO₂ in the year 2010 [78]. If HB Grandi would switch all the ships in this study to run on dual-fuel LNG propulsion the ships would lower the total CO₂ emission from the Icelandic fishing fleet by 10.926 tonnes each year or 2%.

11. Discussion

With stringent regulations on emissions from ships, LNG as a ship fuel is gaining more attention from ship owners because LNG is a cleaner burning and less expensive fuel than conventional oil [6:3]. Some see natural gas as a bridge fuel towards the implementation of renewable energy sources [87:1].

The Icelandic fishing fleet is energy demanding and consumes large amounts of oil each year resulting in high emissions of harmful pollutants. With oil price increases past years and imposed carbon tax on fossil fuels the Icelandic fishing fleet could benefit from switching to a cheaper more environmentally friendly fuel.

The main problems related to the use of LNG as a ship fuel is the lack of existing infrastructure, the extra space needed onboard the ships and the high investment cost needed for converting existing ships as well as the added investment cost imposed on new ships.

The lack of infrastructure has to be solved for LNG to expand as a ship fuel because ship owners will not invest in new ships running on LNG or convert existing ships unless there is a secure supply of the fuel at a reasonable price. For this study it was assumed that an infrastructure had been established in Iceland with sufficient supply of LNG to the local ship owners. By equipping the ships with dual-fuel propulsion running either on LNG or MGO the ship owners have fuel flexibility and can run on MGO if LNG is not available in some ports or depending on fuel prices. In the future there is a possibility that oil and gas will be found at the Jan Mayen area within territorial waters of Iceland and then Iceland has its own reserves, but if this becomes a reality it would take a long time before these reserves could be utilized [88].

Much additional space is required onboard ships using LNG as a fuel [14:20]. With a new built ship the space demand for the LNG system would not be a problem because then the space required is already a part of the design. For the ships in this study it was estimated that the additional space required with a conversion to dual-fuel LNG propulsion would not be a problem because of the large volume of existing tank space already onboard the ships, but whether that space could be utilized for the LNG tank and tank room needed an engineer has to determine.

The investment cost of switching to LNG propulsion is high, the added investment cost imposed on a new ship and especially the cost of converting an existing ship. It is expected

that the investment cost will go down in the future as increasing number of LNG fuelled ships will be contracted [3:10]. This study showed that of all the ships it would only be feasible to convert the pelagic vessels according to price scenario four and five for Ingunn and price scenario four for Faxi and Lundey with a long payback period. The reason for this is the large amount of MGO the ships consumed last year and the low proportion of MGO still needed after a conversion. Therefore high operational savings was gained for these two price scenario. It is unlikely that the ship owner would take the risk of convert Faxi and Lundey, and assume that the price for LNG would always stay low against a high MGO price.

The parts that are replaced during a conversion are the same parts replaced during a normal maintenance of the ships engine [89:21], therefore some of the investment cost for the conversion of the engine could be leveled out and the investment cost reduced. This reduction of the investment cost could influence the NPV calculations for the feasibility of a conversion of the ships.

The changes in investment cost are not the only influencing factors on the economic feasibility, the changes in fuel prices play a big role. That is the reason for using 6 price scenarios for the MGO and LNG prices in this study.

The NPV for all the ships was always positive for the added investment cost of a new ship when the price for MGO was "High" against the three price levels for LNG. When the price for MGO was "Central" against the three price levels for LNG the NPV was positive for all the ships when the price for the LNG was "Low" but only for Ingunn, Sturlaugur and Ásbjörn when the LNG price was "Central". The NPV for a conversion was only feasible for the pelagic vessels according to price scenarios four and five ("Low" or "Central" LNG price against a "High" MGO price). The pelagic vessels also showed higher positive NPV at the end of 20 years compared to the wetfish trawlers for the same price scenarios.

The reason for the pelagic vessels being more economically feasible than the wetfish trawlers is that the pelagic vessels consume more fuel annually and due to lower operation time at high engine loads less MGO in proportion to LNG would be needed after a switch to dual-fuel propulsion resulting in higher operational savings.

In this study the NPV of the investment was calculated over the economic lifetime of 20 years with a discount rate of 10%. The lifetime of ships are usually much longer than 20 years. The lifetime is relative and depends heavily on the maintenance and equipment renewal. It was

estimated according to the vessel supervisor at HB Grandi that all the ships in this study should last the next 10-15 years, but if reconstructed they could last for the next 25 years. The wetfish trawlers are today 32-35 years old. The pelagic vessel Ingunn is only 13 years old, Faxi is 26 years old and Lundey is 53 years old. Both Faxi and Lundey have recently had a major reconstruction to prolong their lifetime, see e-mail in Appendix 10.8. If the lifetime of a ship is at least 40-50 years the ship owners may accept a longer payback period than 20 years for the added investment cost of a new ship that has lower operational cost and is more environmentally friendly.

The results showed that where the NPV was positive the payback period was long (never shorter than 7 years). The payback period could be shortened if the ship owner would settle for a lower discount rate than 10% . Once the investment has been paid up the operational savings would become a financial gain for the ship owner.

The financial aspect should not be the only concern because the results show that significant emission reduction would be gained by switching to LNG as a fuel. The fishing companies could with that lower the environmental footprint of their company and its products. Even though the operational savings gained would not cover the investment needed some companies could look at this as an investment in rising the image of their company as well as contributing to a cleaner environment.

The Icelandic fishing fleet is releasing large amount of harmful pollutants every year. It is apparent (from Figure 30) that the Icelandic government needs to take some action if they want lower the GHG emission from the fishing fleet and follow their goals on GHG reduction. Even though the GHG emission from the fishing fleet lowered in the year 2010 as a result of the recession in the economy since 2008, the emission is likely to go up again once the economy starts to recover. The government has implemented a carbon tax in 2009 but will that be enough? Will that reduce the oil use of the fishing fleet? It could push towards a switch to alternative fuels such as LNG if the fishing companies see financial benefits in doing so.

When Iceland confirms the MARIPOL Annex VI the Icelandic coastal areas could become ECA in the future forcing ship owners to reduce emission. The government could take their actions further to show that an emission reduction from the fishing fleet is essential by offer some kind of subsidies to ship owners to support a switch to a more environmentally friendly fuel, such as LNG.

12. Conclusion

This feasibility study shows that it is environmentally feasible for ship owners to switch to dual-fuel LNG propulsion. This can be of great importance in reducing GHG emission as well as contributing to a cleaner environment.

The study shows that the ships that consumed most of MGO annually last year need less proportion of MGO versus LNG after a switch to dual-fuel LNG. These ships are the wetfish trawler Sturlaugur and the pelagic vessel Ingunn. These ships also showed the best economic and environmental feasibility compared to the other ships of the same type. This concludes that increased oil consumption strengthens the advantage of LNG as a fuel for ships.

While the price for MGO is at current price it would only be feasible to add to the investment cost of a new ship with dual-fuel LNG propulsion in the case of Sturlaugur and Ásbjörn if the price for LNG would be "Low" or "Central". For the wetfish trawler Ottó the added investment cost of a new trawler would only be feasible at current MGO price against a "Low" LNG price.

If the price for MGO in Iceland will go up to the estimated price level "High" according to this study it would be economically feasible for HB Grandi to add to the investment cost of all the wetfish trawlers if they were to renew those ships.

Due to the high investment cost needed for a conversion it would not be considered economically feasible to convert the existing wetfish trawlers in this study to run on dual-fuel LNG propulsion.

For the pelagic vessels it would only be feasible to add to the investment cost of a new ship with dual-fuel LNG propulsion in the case of Ingunn if the price for MGO is at current price against a "Low" or "Central" LNG price. For Lundey and Faxi the added investment cost of a new ship would only be feasible at current MGO price against a "Low" LNG price.

If the price for MGO in Iceland will go up to the estimated price level "High" according to this study it would be economically feasible for HB Grandi to add to the investment cost of all the pelagic vessels. The payback period would be similar as for the wetfish trawlers but the NPV at the end of 20 years would be higher resulting in greater feasibility.

Due to the high operational savings gained the pelagic vessel Ingunn would be feasible for a conversion to dual-fuel LNG propulsion if the MGO price will rise up to the "High"

estimation price in this study against a "Low" or "Central" LNG price. For Lundey and Faxi the conversion would only be feasible if the price for MGO would be "High" against a "Low" LNG price. If the price for the MGO is at current price it would not be considered feasible to convert the existing pelagic vessels to dual-fuel LNG propulsion.

Whether it would be a feasible option for the Icelandic fishing ship owners depends heavily on the LNG and MGO price as well as the ships fuel consumption. If the price for MGO is at current price it could be economically feasible to consider adding to the investment cost of new ships (similar as the ones in this study) with dual-fuel LNG propulsion if the price for LNG will be at price levels "Low" or "Central". However, if the price for MGO continues to rise, as it is expected to do in the future, it could be economically feasibility for the ship owners to add to the investment of new ships at all the three price levels for the LNG. The conversion could be feasible for ships similar to the pelagic vessels size and fuel consumption if the price for MGO would be "High" against a "Low" or "Central" LNG price.

It should be noted that the results in this study only apply to the selected ships and should not be assessed as a general statement for all ships. The results will vary between ship types and their fuel consumption and should be analyzed from case to case. This study could lead to further investigations of different type of ships within the Icelandic fleet to switch to LNG propulsion, whether they are fishing ships, cargo ships or ferries.

Currently no infrastructure for LNG exists in Iceland and if ship owners are willing to switch to LNG propulsion such an infrastructure has to be established where LNG can be bought at a reasonable price similar to the ones in this study.

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14. Appendices

Appendix 1. Emission Control Areas



Appendix 2. Fuel use Coefficient

Fishing method	Open boats kg oil/kg fish	Decked vessels kg oil/kg fish	Trawlers kg oil/kg fish
Total catch	0,136		
Line		0,119	
Nets		0,119	
Handline		0,119	
Seine nets		0,153	
Bottom trawl		0,297	0,416
Pelagic trawl (Herring)		0,051	
Pelagic trawl (Capelin)		0,027	
Pelagic trawl (Blue whiting)		0,075	
Nephrops trawl		0,361	
Purse seine (Herring)		0,070	
Purse seine (Capelin)		0,017	
Shrimp trawl		0,722	0,908
Redfish trawls			0,446

*based on MGO density of 0,848 kg/liter.

Appendix 3. Port cases

Main characteristics of three port cases providing LNG as bunker fuel.

LNG Port Case	Large scale - Case I	Medium scale - Case II	Small-scale - Case III
Throughput	204 000 m ³ /yr	343 000 m ³ /yr	52 000 m ³ /yr
Tank size	(no separate tank)	20 000 m ³	2* 700 m ³
Tank turnover/year	n/a	20	44
Installations for import, bunkering and other transfer to end-users	<p>One bunkering berth including one jetty (pier for mooring) and associated equipment.</p> <p>One small scale bunkering vessel, 4 000 m³; Two tank trucks, 50 m³ each.</p> <p>One LNG tank-truck filling station;</p>	<p>One bunkering berth including one jetty (pier for mooring) and associated equipment.</p> <p>Two small scale bunkering vessels, 3 000 m³ and 4 000 m³; One tank truck, 50 m³.</p> <p>One LNG tank-truck filling station;</p>	<p>One bunkering berth and associated equipment.</p> <p>One tank truck, 50 m³.</p> <p>One LNG tank-truck filling station;</p>

Appendix 4. General Information

General information about ships and energy demand.



Photograph: Arnbjörn Eiríksson

General information		Energy demand	
Name:	Ásbjörn RE-050	Engine power:	1450 kW
Registration nr.:	1509	Engine type:	Werkspoor
Type:	Wetfish trawler	Auxiliary power:	2 Volvo Penta, 180 kW each
Built:	1978		2 Stamford generators 168 kW each
Length:	44,9 m	Total installed power:	1810 kW
Beam:	9,5 m		
Depth:	6,6 m		
Gross tonnage:	652 GT	MGO consumed last year:	1.320.101 liters = 1.104 tonnes
Days out at sea last year:	300	MGO/voyage:	27.968 liters = 23,4 tonnes
Average length of voyage:	6,4 days	Size of existing fuel tanks:	144.000 liters = 144 m ³
Voyages/year:	47,2		

Note: The average length of voyages is with a 20% margin.



Photograph: Kristján Maack

General information		Energy demand	
Name:	Ottó Þorláksson	Engine power:	1619 kW
Registration nr.:	1578	Engine type:	M.A.K
Type:	Wetfish trawler		
Built:	1981	Auxiliary power:	Catepillar 440 kW
Length:	50,6 m	Total installed power:	2059 kW
Beam:	10,3 m		
Depth:	7,3 m	MGO consumed last year:	1.424.859 liters = 1.191 tonnes
Gross tonnage:	879 GT	MGO/voyage:	34.632 liters = 29 tonnes
Days out at sea last year:	288	Size of existing fuel tanks:	180.000 liters = 180 m ³
Average length of voyage:	7 days		
Voyages/year:	41,1		



Photograph: Kristján Maack

General information		Energy demand	
Name:	Ingunn AK-150	Engine power:	4320 kW
Registration nr.:	2388	Engine type:	M.A.K
Type:	Pelagic vessel	Auxiliary power:	Catepillar 345 kW
Built:	2000		Catepillar 530 kW
Length:	65,2 m		Generator 2240 kW
Beam:	12,6 m	Total installed power:	5195 kW
Depth:	8,4 m		
Gross tonnage:	1981 GT		
Days out at sea last year:	211	MGO consumed last year:	2.154.937 liters = 1.802 tonnes
Average length of voyage:	4,87 days	MGO/voyage:	50.115 liters = 42 tonnes
Voyages/year:	43,3	Size of existing fuel tanks:	400.000 liters = 400 m ³



Photograph: Þorgeir Baldursson

General information		Energy demand	
Name:	Faxi RE-9	Engine power:	4140 kW
Registration nr.:	1742	Engine type:	Wartsila
Type:	Pelagic vessel	Auxiliary power:	Mitsubishi 397 kW
Built:	1987		Mitsubishi 397 kW
Length:	60,3 m		Generator 2000 kW
Beam:	11,0 m	Total installed power:	5064 kW
Depth:	8,0 m		
Gross tonnage:	1411 GT		
Days out at sea last year:	202	MGO consumed last year:	1.810.276 liters = 1.513 tonnes
Average length of voyage:	4,75 days	MGO/voyage:	42.100 liters = 35 tonnes
Voyages/year:	42,5	Size of existing fuel tanks:	340.000 liters = 340 m ³



Photograph: Kristján Maack

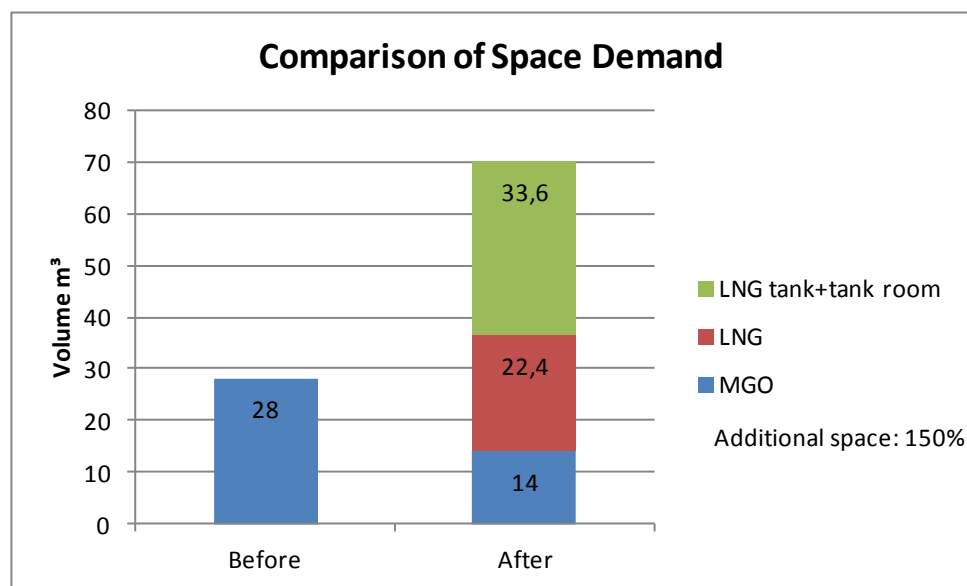
General information		Energy demand	
Name:	Lundey NS-14	Engine power:	4920 kW
Registration nr.:	155	Engine type:	Wartsila
Type:	Pelagic vessel	Auxiliary power:	Mitsubishi 610 kW
Built:	1960		Generator 2500 kW
Length:	62,9 m	Total installed power:	5530 kW
Beam:	10,4 m		
Depth:	7,94 m		
Gross tonnage:	1424 GT	MGO consumed last year:	1.998.813 liters = 1.671 tonnes
Days out at sea last year:	218	MGO/voyage:	43.552 liters = 36,4 tonnes
Average length of voyage:	4,75 days	Size of existing fuel tanks:	280.000 liters = 280 m ³
Voyages/year:	45,9		

Appendix 5. Energy and Space Demand

Fuel demand and the tank space needed after a switch to dual-fuel LNG propulsion.

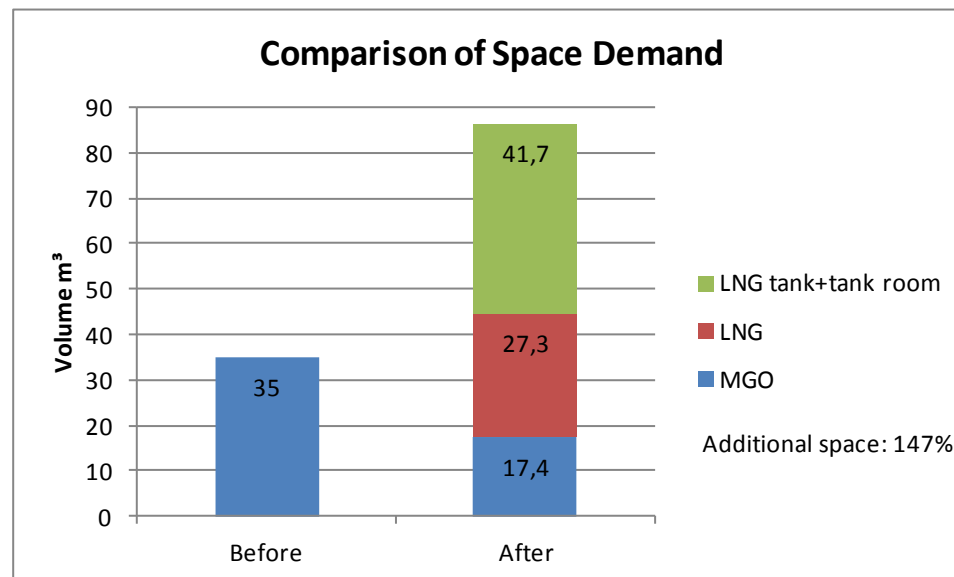
Ásbjörn RE-50		
Fuel demand after a switch to Dual-fuel		
MGO at high loads	Liters	Tonnes
per voyage	13.889	11,6
per year	655.561	548,0
MGO as ignition source for LNG	Liters	Tonnes
per voyage	88,0	0,07
per year	4.154	3,5
Total MGO demand	Liters	Tonnes
per voyage	13.977	11,7
per year	659.714	551,5
LNG demand	Liters	Tonnes
per voyage	22.415	9,9
per year	1.057.988	465,5

Space demand		
Existing tank space : 144 m ³		
Before	Running only on MGO	28 m ³
After	MGO still needed	14 m ³
	LNG bunkering volume	22,4 m ³
	LNG Tank volume within (90% filling ratio)	25 m ³
	LNG fuel, tank and tank room	56 m ³
	Total space needed for MGO and LNG:	70 m ³
Additional space needed after a change to dual-fuel:		42 m ³



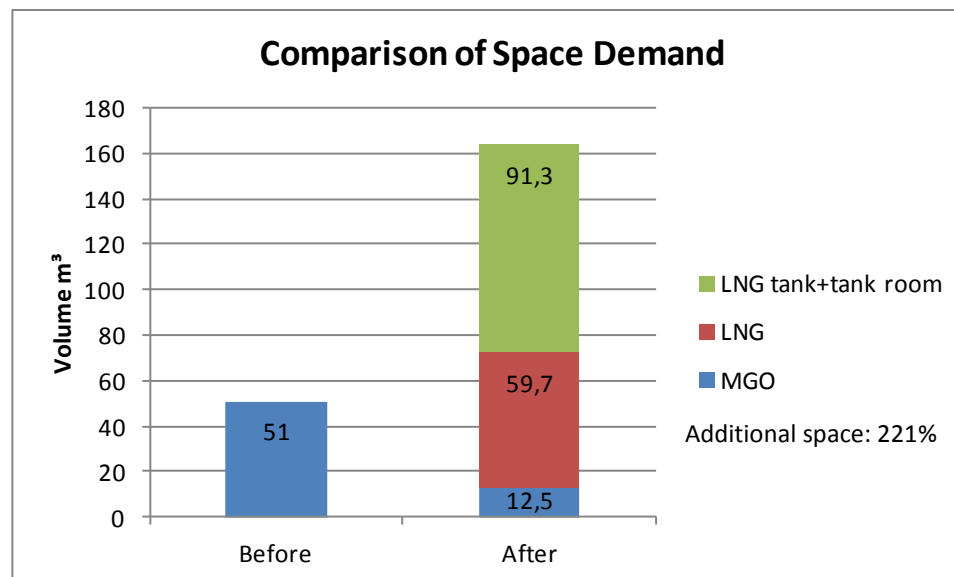
Ottó N. Þorláksson RE-203		
Fuel demand after a change to Dual-fuel		
MGO at high loads	Liters	Tonnes
per voyage	17.286	14,5
per year	711.195	594,6
MGO as ignition source for LNG	Liters	Tonnes
per voyage	107	0,09
per year	4.411	3,7
Total MGO demand	Liters	Tonnes
per voyage	17.393	14,5
per year	715.606	598,2
LNG demand	Liters	Tonnes
per voyage	27.266	12,0
per year	1.121.801	493,6

Space demand		
Existing tank space : 180 m ³		
Before	Running only on MGO	35 m ³
After	MGO still needed	17,4 m ³
	LNG bunkering volume	27,3 m ³
	LNG Tank volume within (90% filling ratio)	30 m ³
	LNG fuel, tank and tank room	69 m ³
	Total space needed for MGO+LNG:	87 m ³
Additional space needed after a change to dual-fuel:		52 m ³



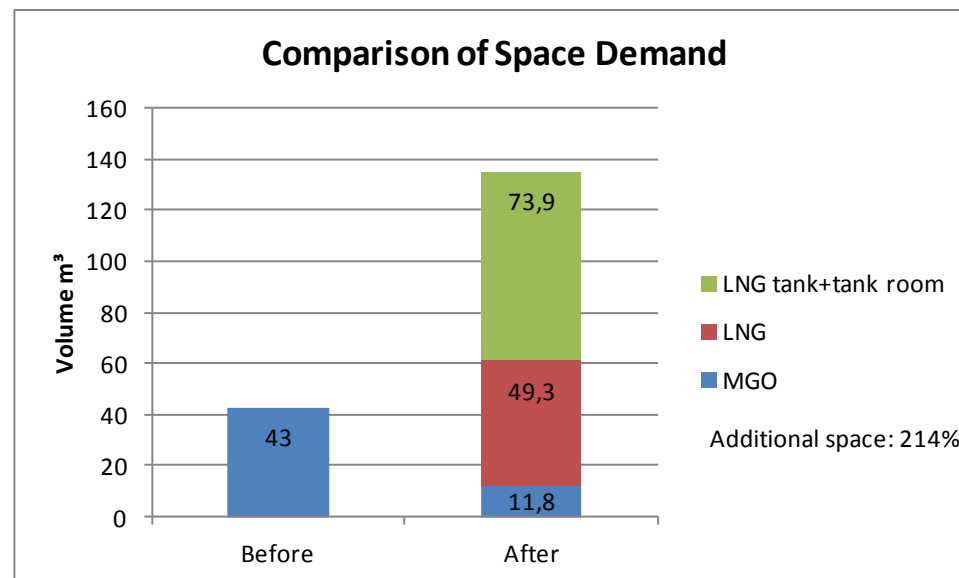
Ingunn AK-150		
Fuel demand after a change to Dual-fuel		
MGO at high loads	Liters	Tonnes
per voyage	12.212	10,2
per year	529.103	442,3
MGO as ignition source for LNG	Liters	Tonnes
per voyage	234,7	0,20
per year	10.169	8,5
Total MGO demand	Liters	Tonnes
per voyage	12.447	10,4
per year	539.272	450,8
LNG demand	Liters	Tonnes
per voyage	59.698	26,3
per year	2.586.505	1138,1

Space demand		
Exsisting tank space : 400 m ³		
Before	Running only on MGO	51 m ³
After	MGO still needed	12,5 m ³
	LNG bunkering volume	59,7 m ³
	LNG Tank volume within (90% filling ratio)	66,3 m ³
	LNG fuel, tank and tank room	151 m ³
	Total space needed for MGO+LNG:	163,5 m ³
Additional space needed after a change to dual-fuel:		112,5 m³



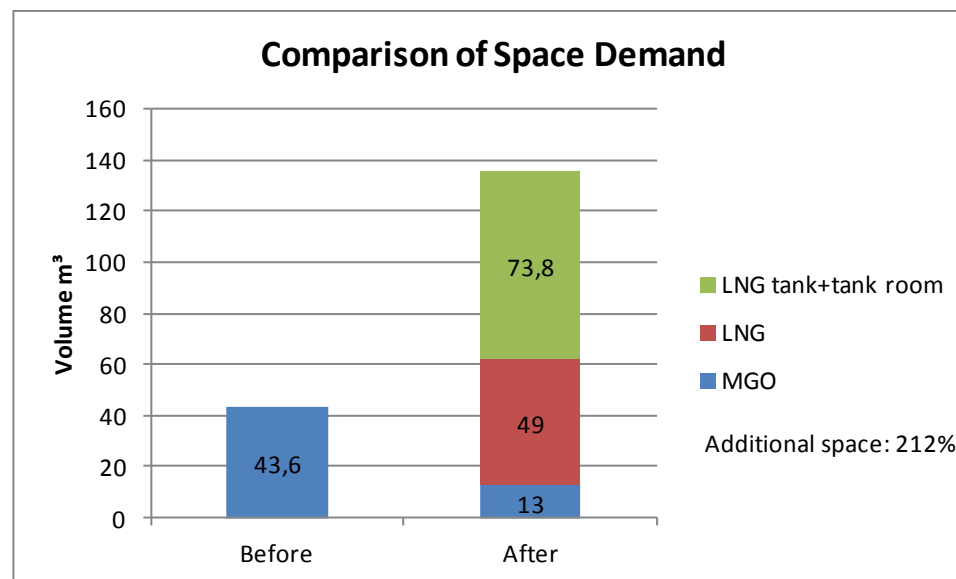
Faxi RE-9		
Fuel demand after a change to Dual-fuel		
MGO at high loads	Liters	Tonnes
per voyage	11.611	9,7
per year	493.773	412,8
MGO as ignition source for LNG	Liters	Tonnes
per voyage	194	0,16
per year	8.233	6,9
Total MGO demand	Liters	Tonnes
per voyage	11.805	9,9
per year	502.006	419,7
LNG demand	Liters	Tonnes
per voyage	49.251	21,7
per year	2.094.464	921,6

Space demand		
Existing tank space : 340 m ³		
Before	Running only on MGO	43 m ³
After	MGO still needed	11,8 m ³
	LNG bunkering volume	49,3 m ³
	LNG Tank volume within (90% filling ratio)	54,8 m ³
	LNG fuel, tank and tank room	123,2 m ³
	Total space needed for MGO+LNG:	135 m ³
Additional space needed after a change to dual-fuel:		92 m ³



Lundey NS-14		
Fuel demand after a change to Dual-fuel		
MGO at high loads	Liters	Tonnes
per voyage	12.679	10,6
per year	581.899	486,5
MGO as ignition source for LNG	Liters	Tonnes
per voyage	193	0,16
per year	8.862	7,4
Total MGO demand	Liters	Tonnes
per voyage	12.872	10,8
per year	590.762	493,9
LNG demand	Liters	Tonnes
per voyage	49.117	21,6
per year	2.254.212	991,9

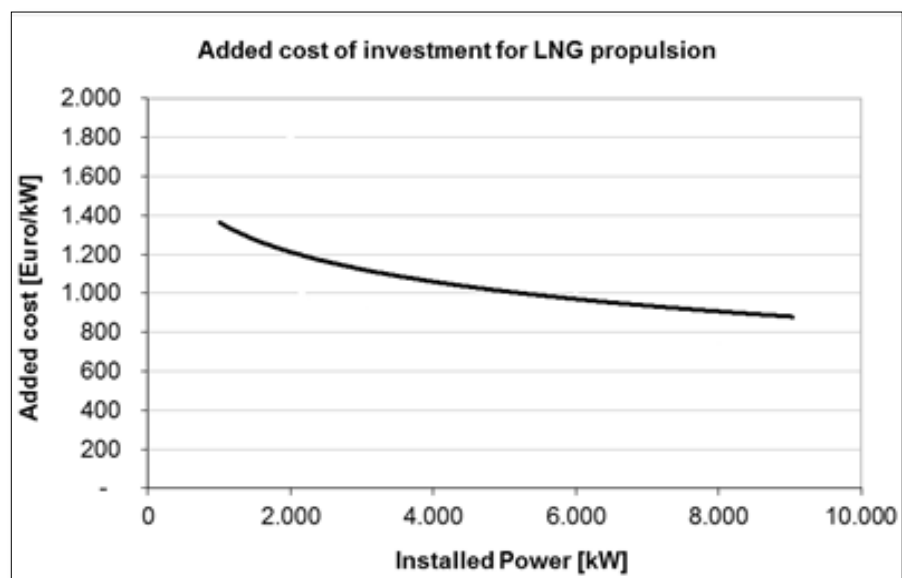
Space demand		
Exsisting tank space : 280 m ³		
Before	Running only on MGO	43,6 m ³
After	MGO still needed	13 m ³
	LNG bunkering volume	49 m ³
	LNG Tank volume within (90% filling ratio)	54,4 m ³
	LNG fuel, tank and tank room	122,8 m ³
	Total space needed for MGO+LNG:	135,8 m ³
Additional space needed after a change to dual-fuel:		92,2 m ³



Appendix 6. Investment Cost

The added investment cost of a **new ship** with a dual-fuel LNG propulsion.

Name	Installed power (kW)	Added cost €/kW	Added cost of investment
Ásbjörn	1810	1200	2.172.000 €
Ottó N. Þorláksson	2059	1200	2.470.800 €
Ingunn	5195	1000	5.195.000 €
Faxi	5064	1000	5.064.000 €
Lundey	5530	950	5.253.500 €



Appendix 7. Operational Cost

Annual maintenance cost before and after a switch to dual-fuel LNG propulsion, expressed in thousand EUR.

Vessel	Maintenance cost per year		
	Before	Dual-fuel adds 5%	After
Ásbjörn RE-50	135,6 €	6,8 €	142,4 €
Ottó N. Þorláksson RE-203	293,5 €	14,7 €	308,1 €
Ingunn AK-150	256,9 €	12,8 €	269,8 €
Faxi RE-9	342,7 €	17,1 €	359,9 €
Lundey NS-14	259,7 €	13,0 €	272,7 €

Wetfish trawlers

Annual fuel cost before and after a switch to dual-fuel LNG propulsion, fuel savings, added cost of maintenance and total operational savings expressed in thousand EUR:

Ásbjörn RE-50					
Scenario name	Before:	After:			
	MGO Only	Dual-fuel	Fuel Savings	Added cost for maint.	Total operational savings
1.	1.151 €	828 €	323 €	6,8 €	316 €
2.	1.151 €	886 €	265 €	6,8 €	258 €
3.	1.151 €	947 €	204 €	6,8 €	198 €
4.	1.382 €	943 €	438 €	6,8 €	432 €
5.	1.382 €	1.001 €	380 €	6,8 €	373 €
6.	1.382 €	1.062 €	320 €	6,8 €	313 €

Ottó N. Þorláksson AK-10					
Scenario name	Before:	After:			
	MGO Only	Dual-fuel	Fuel Savings	Added cost for maint.	Total operational savings
1.	1.242 €	892 €	350 €	14,7 €	336 €
2.	1.242 €	954 €	289 €	14,7 €	274 €
3.	1.242 €	1.018 €	224 €	14,7 €	210 €
4.	1.491 €	1.017 €	474 €	14,7 €	459 €
5.	1.491 €	1.079 €	412 €	14,7 €	398 €
6.	1.491 €	1.143 €	348 €	14,7 €	334 €

Pelagic vessels

Ingunn AK-150					
Scenario name	Before:	After:			
	MGO Only	Dual-fuel	Fuel Savings	Added cost for maint.	Total operational savings
1.	1.879 €	1.088 €	791 €	12,8 €	778 €
2.	1.879 €	1.230 €	649 €	12,8 €	636 €
3.	1.879 €	1.378 €	501 €	12,8 €	488 €
4.	2.256 €	1.182 €	1.074 €	12,8 €	1.061 €
5.	2.256 €	1.325 €	931 €	12,8 €	919 €
6.	2.256 €	1.473 €	783 €	12,8 €	771 €

Faxi RE-9					
Scenario name	Before:	After:			
	MGO Only	Dual-fuel	Fuel Savings	Added cost for maint.	Total operational savings
1.	1.578 €	938 €	640 €	17,1 €	623 €
2.	1.578 €	1.053 €	525 €	17,1 €	508 €
3.	1.578 €	1.173 €	405 €	17,1 €	388 €
4.	1.894 €	1.026 €	868 €	17,1 €	851 €
5.	1.894 €	1.141 €	753 €	17,1 €	736 €
6.	1.894 €	1.261 €	633 €	17,1 €	616 €

Lundey NS-14					
Scenario name	Before:	After:			
	MGO Only	Dual-fuel	Fuel Savings	Added cost for maint.	Total operational savings
1.	1.743 €	1.054 €	689 €	13,0 €	676 €
2.	1.743 €	1.178 €	565 €	13,0 €	552 €
3.	1.743 €	1.307 €	436 €	13,0 €	423 €
4.	2.092 €	1.157 €	935 €	13,0 €	922 €
5.	2.092 €	1.281 €	811 €	13,0 €	798 €
6.	2.092 €	1.410 €	682 €	13,0 €	669 €

Appendix 8. NPV Calculations

New ship	Sturlaugur	DR	10%	Note: expressed in thousand Euros																	
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.354	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361
NPV	-2.354	-2.026	-1.728	-1.457	-1.210	-986	-782	-597	-428	-275	-136	-10	105	210	305	391	470	541	606	665	719
IRR								2%	5%	7%	9%	10%	11%	12%	12%	13%	13%	14%	14%	14%	14%
													PBP								
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.354	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294
NPV	-2.354	-2.087	-1.844	-1.623	-1.422	-1.240	-1.074	-923	-786	-661	-548	-445	-351	-266	-189	-118	-54	4	57	105	149
IRR									0%	2%	4%	6%	7%	8%	9%	9%	10%	10%	10%	11%	11%
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.354	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227
NPV	-2.354	-2.148	-1.960	-1.790	-1.635	-1.494	-1.366	-1.249	-1.143	-1.047	-960	-880	-808	-742	-682	-628	-578	-534	-493	-456	-422
IRR												1%	2%	3%	4%	5%	6%	6%	7%	7%	7%
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.354	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493
NPV	-2.354	-1.906	-1.499	-1.128	-792	-486	-207	46	276	485	675	848	1.005	1.148	1.277	1.395	1.503	1.600	1.689	1.770	1.843
IRR						2%	7%	11%	13%	15%	16%	17%	18%	19%	19%	19%	20%	20%	20%	20%	20%
								PBP													
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.354	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426
NPV	-2.354	-1.967	-1.615	-1.295	-1.004	-740	-499	-280	-82	99	263	412	548	672	784	886	978	1.063	1.139	1.209	1.272
IRR							2%	6%	9%	11%	13%	14%	15%	15%	16%	16%	17%	17%	17%	17%	17%
										PBP											
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.354	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
NPV	-2.354	-2.027	-1.730	-1.459	-1.213	-990	-787	-602	-434	-281	-142	-16	99	203	298	384	462	533	598	657	710
IRR								2%	5%	7%	9%	10%	11%	12%	12%	13%	13%	14%	14%	14%	14%
													PBP								

Conversion	Sturlaugur	DR	10%	Note: expressed in thousand Euros																	
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361
NPV	-5.000	-4.672	-4.373	-4.102	-3.856	-3.632	-3.428	-3.243	-3.074	-2.921	-2.782	-2.655	-2.540	-2.436	-2.341	-2.254	-2.176	-2.104	-2.039	-1.980	-1.927
IRR															0%	1%	2%	2%	3%	3%	4%
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294	294
NPV	-5.000	-4.733	-4.490	-4.269	-4.068	-3.886	-3.720	-3.569	-3.432	-3.307	-3.193	-3.090	-2.997	-2.912	-2.834	-2.764	-2.700	-2.642	-2.589	-2.541	-2.497
IRR																		0%	1%	1%	2%
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227	227
NPV	-5.000	-4.794	-4.606	-4.435	-4.280	-4.139	-4.011	-3.895	-3.789	-3.693	-3.605	-3.526	-3.453	-3.388	-3.328	-3.273	-3.224	-3.179	-3.138	-3.101	-3.067
IRR																					
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493	493
NPV	-5.000	-4.552	-4.144	-3.774	-3.437	-3.131	-2.853	-2.600	-2.370	-2.161	-1.971	-1.798	-1.641	-1.498	-1.368	-1.250	-1.143	-1.045	-957	-876	-803
IRR											0%	1%	3%	4%	5%	5%	6%	6%	7%	7%	8%
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426
NPV	-5.000	-4.613	-4.261	-3.941	-3.650	-3.385	-3.145	-2.926	-2.727	-2.547	-2.382	-2.233	-2.097	-1.974	-1.862	-1.760	-1.667	-1.583	-1.506	-1.437	-1.373
IRR													0%	1%	2%	3%	4%	4%	5%	5%	6%
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
NPV	-5.000	-4.673	-4.375	-4.105	-3.859	-3.635	-3.432	-3.247	-3.079	-2.927	-2.788	-2.662	-2.547	-2.443	-2.348	-2.262	-2.183	-2.112	-2.047	-1.989	-1.935
IRR															0%	1%	2%	2%	3%	3%	4%

New ship	Ottó N.P.	DR	10%	Note: expressed in thousand Euros																	
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.471	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336
NPV	-2.471	-2.165	-1.888	-1.635	-1.406	-1.197	-1.007	-835	-678	-536	-406	-288	-181	-84	4	85	158	224	285	340	390
IRR										4%	6%	7%	8%	9%	10%	11%	11%	11%	12%	12%	12%
															PBP						
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.471	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274
NPV	-2.471	-2.222	-1.995	-1.789	-1.602	-1.432	-1.277	-1.137	-1.009	-893	-787	-691	-604	-524	-452	-387	-327	-273	-224	-179	-138
IRR										0%	2%	3%	5%	6%	6%	7%	8%	8%	9%	9%	9%
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.471	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210
NPV	-2.471	-2.280	-2.106	-1.949	-1.805	-1.675	-1.556	-1.448	-1.350	-1.261	-1.180	-1.107	-1.040	-979	-924	-874	-828	-786	-749	-714	-683
IRR													0%	1%	2%	3%	4%	4%	5%	5%	6%
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.471	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459
NPV	-2.471	-2.054	-1.674	-1.329	-1.016	-731	-472	-236	-22	173	350	510	657	790	911	1.020	1.120	1.211	1.294	1.369	1.437
IRR							3%	7%	10%	12%	13%	14%	15%	16%	16%	17%	17%	17%	18%	18%	18%
										PBP											
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.471	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398
NPV	-2.471	-2.109	-1.780	-1.481	-1.209	-962	-737	-533	-347	-179	-25	114	241	356	461	556	643	722	793	858	918
IRR								3%	6%	8%	10%	11%	12%	13%	13%	14%	14%	14%	15%	15%	15%
												PBP									
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.471	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334
NPV	-2.471	-2.167	-1.891	-1.640	-1.412	-1.205	-1.016	-845	-689	-547	-419	-301	-195	-98	-10	70	142	208	268	323	373
IRR									2%	4%	6%	7%	8%	9%	10%	10%	11%	11%	12%	12%	12%
																PBP					

Conversion	Ottó N.P.	DR		10%		Note: expressed in thousand Euros																
Price scenario 1:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.000	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	
NPV	-5.000	-4.695	-4.417	-4.164	-3.935	-3.726	-3.537	-3.364	-3.207	-3.065	-2.935	-2.818	-2.711	-2.613	-2.525	-2.444	-2.371	-2.305	-2.244	-2.189	-2.139	
IRR																0%	1%	2%	2%	3%	3%	
Price scenario 2:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.000	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	
NPV	-5.000	-4.751	-4.524	-4.319	-4.131	-3.961	-3.807	-3.666	-3.538	-3.422	-3.316	-3.220	-3.133	-3.054	-2.982	-2.916	-2.856	-2.802	-2.753	-2.708	-2.667	
IRR																			0%	0%	1%	
Price scenario 3:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.000	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	
NPV	-5.000	-4.809	-4.636	-4.478	-4.334	-4.204	-4.085	-3.978	-3.880	-3.791	-3.710	-3.636	-3.569	-3.508	-3.453	-3.403	-3.357	-3.315	-3.278	-3.243	-3.212	
IRR																						
Price scenario 4:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.000	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	
NPV	-5.000	-4.583	-4.203	-3.859	-3.545	-3.260	-3.001	-2.765	-2.551	-2.357	-2.180	-2.019	-1.873	-1.740	-1.619	-1.509	-1.409	-1.318	-1.236	-1.161	-1.092	
IRR												0%	2%	3%	4%	4%	5%	5%	6%	6%	7%	
Price scenario 5:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.000	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	
NPV	-5.000	-4.638	-4.309	-4.010	-3.738	-3.491	-3.267	-3.062	-2.877	-2.708	-2.554	-2.415	-2.288	-2.173	-2.068	-1.973	-1.886	-1.807	-1.736	-1.671	-1.612	
IRR														0%	1%	2%	3%	4%	4%	5%	5%	
Price scenario 6:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.000	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	334	
NPV	-5.000	-4.696	-4.420	-4.169	-3.941	-3.734	-3.545	-3.374	-3.218	-3.076	-2.948	-2.831	-2.724	-2.627	-2.540	-2.460	-2.387	-2.321	-2.261	-2.206	-2.156	
IRR																0%	1%	1%	2%	3%	3%	

New ship	Ásbjörn	DR	10%	Note: expressed in thousand Euros																	
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.172	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316
NPV	-2.172	-1.885	-1.624	-1.386	-1.170	-974	-796	-634	-486	-352	-230	-120	-19	73	156	232	300	363	420	471	518
IRR								0%	4%	6%	7%	9%	10%	11%	11%	12%	12%	13%	13%	13%	13%
														PBP							
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.172	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258
NPV	-2.172	-1.937	-1.724	-1.530	-1.354	-1.194	-1.048	-916	-796	-686	-587	-496	-414	-339	-271	-210	-153	-102	-56	-14	24
IRR										1%	3%	5%	6%	7%	8%	8%	9%	9%	10%	10%	10%
																				PBP	
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.172	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198
NPV	-2.172	-1.992	-1.828	-1.680	-1.544	-1.421	-1.310	-1.208	-1.116	-1.032	-955	-886	-823	-766	-713	-666	-623	-584	-548	-516	-486
IRR												0%	1%	3%	3%	4%	5%	5%	6%	6%	7%
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.172	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432
NPV	-2.172	-1.779	-1.422	-1.098	-803	-534	-291	-69	133	316	482	634	772	897	1.010	1.114	1.208	1.293	1.371	1.442	1.506
IRR						0%	5%	9%	12%	14%	15%	16%	17%	17%	18%	18%	19%	19%	19%	19%	19%
									PBP												
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.172	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373
NPV	-2.172	-1.833	-1.525	-1.244	-990	-758	-547	-356	-182	-24	120	251	370	478	576	665	746	820	887	948	1.004
IRR							1%	5%	8%	10%	11%	12%	13%	14%	15%	15%	15%	16%	16%	16%	16%
											PBP										
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-2.172	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313
NPV	-2.172	-1.887	-1.629	-1.394	-1.180	-985	-809	-648	-502	-369	-249	-139	-39	51	134	209	277	339	395	446	493
IRR								0%	3%	6%	7%	9%	10%	10%	11%	12%	12%	12%	13%	13%	13%
														PBP							

Conversion	Ásbjörn	DR	10%	Note: expressed in thousand Euros																	
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316	316
NPV	-5.000	-4.713	-4.452	-4.214	-3.998	-3.802	-3.624	-3.462	-3.314	-3.180	-3.058	-2.948	-2.847	-2.755	-2.672	-2.596	-2.528	-2.465	-2.408	-2.357	-2.310
IRR																	0%	1%	1%	2%	2%
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258	258
NPV	-5.000	-4.765	-4.552	-4.358	-4.182	-4.022	-3.876	-3.744	-3.624	-3.514	-3.415	-3.324	-3.242	-3.167	-3.099	-3.038	-2.981	-2.930	-2.884	-2.842	-2.804
IRR																				0%	0%
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198	198
NPV	-5.000	-4.820	-4.656	-4.508	-4.372	-4.249	-4.138	-4.036	-3.944	-3.860	-3.783	-3.714	-3.651	-3.594	-3.541	-3.494	-3.451	-3.412	-3.376	-3.344	-3.314
IRR																					
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432
NPV	-5.000	-4.607	-4.250	-3.926	-3.631	-3.362	-3.119	-2.897	-2.695	-2.512	-2.346	-2.194	-2.056	-1.931	-1.818	-1.714	-1.620	-1.535	-1.457	-1.386	-1.322
IRR													1%	2%	3%	3%	4%	5%	5%	6%	6%
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373	373
NPV	-5.000	-4.661	-4.353	-4.072	-3.818	-3.586	-3.375	-3.184	-3.010	-2.852	-2.708	-2.577	-2.458	-2.350	-2.252	-2.163	-2.082	-2.008	-1.941	-1.880	-1.824
IRR														0%	1%	1%	2%	3%	3%	4%	4%
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.000	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313	313
NPV	-5.000	-4.715	-4.457	-4.222	-4.008	-3.813	-3.637	-3.476	-3.330	-3.197	-3.077	-2.967	-2.867	-2.777	-2.694	-2.619	-2.551	-2.489	-2.433	-2.382	-2.335
IRR																	0%	1%	1%	2%	2%

New ship	Ingunn	DR		10%		Note: expressed in thousand Euros															
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.195	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778
NPV	-5.195	-4.488	-3.845	-3.260	-2.729	-2.246	-1.807	-1.407	-1.044	-714	-415	-142	106	331	536	723	892	1.046	1.186	1.313	1.429
IRR								1%	4%	6%	8%	9%	10%	11%	12%	12%	13%	13%	13%	14%	14%
													PBP								
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.195	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636
NPV	-5.195	-4.617	-4.091	-3.613	-3.179	-2.784	-2.425	-2.099	-1.802	-1.532	-1.287	-1.064	-861	-677	-510	-358	-219	-93	21	125	220
IRR									0%	2%	4%	5%	6%	7%	8%	9%	9%	10%	10%	10%	11%
																		PBP			
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.195	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488
NPV	-5.195	-4.751	-4.348	-3.981	-3.648	-3.345	-3.070	-2.819	-2.592	-2.385	-2.196	-2.025	-1.870	-1.729	-1.600	-1.483	-1.377	-1.280	-1.193	-1.113	-1.040
IRR												1%	2%	3%	4%	5%	5%	6%	6%	7%	7%
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.195	1.061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061
NPV	-5.195	-4.230	-3.354	-2.556	-1.832	-1.173	-574	-30	465	915	1.324	1.696	2.034	2.342	2.621	2.875	3.106	3.316	3.507	3.680	3.838
IRR						1%	6%	10%	12%	14%	16%	17%	17%	18%	19%	19%	19%	19%	20%	20%	20%
									PBP												
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.195	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919
NPV	-5.195	-4.360	-3.600	-2.910	-2.282	-1.711	-1.193	-721	-292	98	452	774	1.067	1.333	1.575	1.795	1.995	2.177	2.342	2.492	2.629
IRR							2%	6%	8%	10%	12%	13%	14%	15%	15%	16%	16%	16%	17%	17%	17%
										PBP											
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.195	771	771	771	771	771	771	771	771	771	771	771	771	771	771	771	771	771	771	771	771
NPV	-5.195	-4.494	-3.857	-3.278	-2.751	-2.272	-1.837	-1.441	-1.082	-755	-458	-187	58	282	485	669	837	990	1.128	1.254	1.369
IRR								1%	4%	6%	8%	9%	10%	11%	12%	12%	13%	13%	13%	14%	14%
													PBP								

Conversion	Ingunn		DR	10%	Note: expressed in thousand Euros																
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778	778
NPV	-7.000	-6.293	-5.650	-5.065	-4.534	-4.051	-3.612	-3.212	-2.849	-2.519	-2.220	-1.947	-1.699	-1.474	-1.269	-1.082	-913	-759	-619	-492	-376
IRR										0%	2%	4%	5%	6%	7%	7%	8%	8%	9%	9%	9%
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636	636
NPV	-7.000	-6.422	-5.896	-5.418	-4.984	-4.589	-4.230	-3.904	-3.607	-3.337	-3.092	-2.869	-2.666	-2.482	-2.315	-2.163	-2.024	-1.898	-1.784	-1.680	-1.585
IRR												0%	1%	2%	3%	4%	5%	5%	6%	6%	7%
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488	488
NPV	-7.000	-6.556	-6.153	-5.786	-5.453	-5.150	-4.875	-4.624	-4.397	-4.190	-4.001	-3.830	-3.675	-3.534	-3.405	-3.288	-3.182	-3.085	-2.998	-2.918	-2.845
IRR															0%	1%	1%	2%	3%	3%	3%
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	1.061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061	1061
NPV	-7.000	-6.035	-5.159	-4.361	-3.637	-2.978	-2.379	-1.835	-1.340	-890	-481	-109	229	537	816	1.070	1.301	1.511	1.702	1.875	2.033
IRR								2%	4%	7%	8%	10%	11%	11%	12%	13%	13%	13%	14%	14%	14%
													PBP								
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919	919
NPV	-7.000	-6.165	-5.405	-4.715	-4.087	-3.516	-2.998	-2.526	-2.097	-1.707	-1.353	-1.031	-738	-472	-230	-10	190	372	537	687	824
IRR									1%	3%	5%	7%	8%	9%	9%	10%	10%	11%	11%	11%	12%
																	PBP				
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	771	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661
NPV	-7.000	-6.299	-5.753	-5.256	-4.805	-4.394	-4.021	-3.682	-3.374	-3.093	-2.838	-2.607	-2.396	-2.205	-2.031	-1.872	-1.729	-1.598	-1.479	-1.371	-1.273
IRR												1%	2%	3%	4%	5%	6%	6%	6%	7%	7%

New ship	Faxi	DR		10%		Note: expressed in thousand Euros																
Price scenario 1:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.064	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	
NPV	-5.064	-4.498	-3.983	-3.515	-3.089	-2.702	-2.351	-2.031	-1.740	-1.476	-1.236	-1.018	-819	-639	-475	-325	-190	-67	45	147	240	
IRR									0%	2%	4%	5%	7%	7%	8%	9%	9%	10%	10%	10%	11%	
																			PBP			
Price scenario 2:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.064	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	
NPV	-5.064	-4.602	-4.182	-3.801	-3.454	-3.138	-2.852	-2.591	-2.354	-2.138	-1.943	-1.765	-1.603	-1.455	-1.322	-1.200	-1.090	-989	-898	-815	-739	
IRR											0%	2%	3%	4%	5%	6%	6%	7%	7%	7%	8%	
Price scenario 3:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.064	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	
NPV	-5.064	-4.711	-4.391	-4.099	-3.834	-3.593	-3.374	-3.175	-2.994	-2.829	-2.680	-2.544	-2.420	-2.308	-2.206	-2.113	-2.028	-1.952	-1.882	-1.818	-1.761	
IRR														0%	1%	2%	3%	3%	4%	4%	4%	
Price scenario 4:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.064	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	
NPV	-5.064	-4.290	-3.587	-2.948	-2.366	-1.838	-1.358	-921	-524	-163	165	463	734	981	1.205	1.409	1.594	1.762	1.915	2.055	2.181	
IRR							0%	4%	7%	9%	11%	12%	13%	14%	14%	15%	15%	15%	16%	16%	16%	
																			PBP			
Price scenario 5:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.064	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	
NPV	-5.064	-4.395	-3.787	-3.234	-2.731	-2.274	-1.859	-1.481	-1.137	-825	-542	-284	-49	164	358	534	694	840	972	1.093	1.202	
IRR								0%	3%	6%	7%	9%	10%	11%	11%	12%	12%	13%	13%	13%	13%	
																			PBP			
Price scenario 6:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-5.064	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	
NPV	-5.064	-4.504	-3.995	-3.532	-3.111	-2.729	-2.381	-2.065	-1.778	-1.516	-1.279	-1.063	-867	-688	-526	-379	-245	-123	-12	89	180	
IRR										2%	4%	5%	6%	7%	8%	9%	9%	10%	10%	10%	11%	
																			PBP			

Conversion	Faxi	DR		10%		Note: expressed in thousand Euros																
Price scenario 1:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-7.000	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	623	
NPV	-7.000	-6.434	-5.919	-5.451	-5.025	-4.638	-4.287	-3.967	-3.676	-3.412	-3.172	-2.954	-2.755	-2.575	-2.411	-2.261	-2.126	-2.003	-1.891	-1.789	-1.696	
IRR												0%	1%	2%	3%	4%	4%	5%	6%	6%	6%	
Price scenario 2:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-7.000	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	508	
NPV	-7.000	-6.538	-6.118	-5.737	-5.390	-5.074	-4.788	-4.527	-4.290	-4.074	-3.879	-3.701	-3.539	-3.391	-3.258	-3.136	-3.026	-2.925	-2.834	-2.751	-2.675	
IRR															0%	1%	2%	2%	3%	3%	4%	
Price scenario 3:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-7.000	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	
NPV	-7.000	-6.647	-6.327	-6.035	-5.770	-5.529	-5.310	-5.111	-4.930	-4.765	-4.616	-4.480	-4.356	-4.244	-4.142	-4.049	-3.964	-3.888	-3.818	-3.754	-3.697	
IRR																			0%	1%	1%	
Price scenario 4:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-7.000	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	851	
NPV	-7.000	-6.226	-5.523	-4.884	-4.302	-3.774	-3.294	-2.857	-2.460	-2.099	-1.771	-1.473	-1.202	-955	-731	-527	-342	-174	-21	119	245	
IRR										2%	4%	5%	6%	7%	8%	9%	9%	10%	10%	10%	11%	
																					PBP	
Price scenario 5:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-7.000	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	736	
NPV	-7.000	-6.331	-5.723	-5.170	-4.667	-4.210	-3.795	-3.417	-3.073	-2.761	-2.478	-2.220	-1.985	-1.772	-1.578	-1.402	-1.242	-1.096	-964	-843	-734	
IRR											1%	3%	4%	5%	6%	6%	7%	7%	8%	8%	8%	
Price scenario 6:																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Cash flow	-7.000	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	616	
NPV	-7.000	-6.440	-5.931	-5.468	-5.047	-4.665	-4.317	-4.001	-3.714	-3.452	-3.215	-2.999	-2.803	-2.624	-2.462	-2.315	-2.181	-2.059	-1.948	-1.847	-1.756	
IRR													1%	2%	3%	4%	4%	5%	5%	6%	6%	

PBP

New ship	Lundey	DR	10%	Note: expressed in thousand Euros																	
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.254	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676
NPV	-5.254	-4.639	-4.080	-3.572	-3.111	-2.691	-2.309	-1.962	-1.647	-1.360	-1.100	-863	-647	-452	-274	-112	35	169	291	401	502
IRR									1%	3%	5%	6%	7%	8%	9%	10%	10%	11%	11%	11%	11%
																	PBP				
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.254	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552
NPV	-5.254	-4.752	-4.295	-3.881	-3.504	-3.161	-2.849	-2.566	-2.309	-2.075	-1.862	-1.668	-1.492	-1.332	-1.187	-1.055	-935	-826	-726	-636	-554
IRR											1%	2%	4%	5%	6%	6%	7%	7%	8%	8%	8%
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.254	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423
NPV	-5.254	-4.869	-4.519	-4.202	-3.913	-3.650	-3.411	-3.194	-2.997	-2.817	-2.654	-2.506	-2.371	-2.249	-2.137	-2.036	-1.944	-1.860	-1.784	-1.715	-1.652
IRR														1%	2%	2%	3%	4%	4%	5%	5%
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.254	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922
NPV	-5.254	-4.415	-3.653	-2.961	-2.331	-1.758	-1.238	-765	-335	56	412	735	1.029	1.296	1.539	1.759	1.960	2.142	2.308	2.459	2.596
IRR							1%	5%	8%	10%	12%	13%	14%	15%	15%	16%	16%	16%	16%	17%	17%
																	PBP				
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.254	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798
NPV	-5.254	-4.528	-3.869	-3.269	-2.724	-2.228	-1.778	-1.369	-996	-658	-350	-70	184	415	625	816	990	1.148	1.291	1.422	1.540
IRR								2%	5%	7%	8%	10%	11%	12%	12%	13%	13%	13%	14%	14%	14%
																	PBP				
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-5.254	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669
NPV	-5.254	-4.645	-4.092	-3.590	-3.133	-2.717	-2.340	-1.997	-1.684	-1.401	-1.143	-908	-695	-501	-325	-165	-19	113	233	343	442
IRR									0%	3%	5%	6%	7%	8%	9%	9%	10%	10%	11%	11%	11%
																	PBP				

Conversion	Lundey		DR	10%	Note: expressed in thousand Euros																
Price scenario 1:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676	676
NPV	-7.000	-6.385	-5.827	-5.319	-4.857	-4.437	-4.056	-3.709	-3.394	-3.107	-2.846	-2.609	-2.394	-2.198	-2.020	-1.858	-1.711	-1.577	-1.456	-1.345	-1.245
IRR												1%	2%	3%	4%	5%	6%	6%	7%	7%	7%
Price scenario 2:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552	552
NPV	-7.000	-6.498	-6.042	-5.627	-5.250	-4.907	-4.596	-4.313	-4.055	-3.821	-3.608	-3.415	-3.239	-3.079	-2.934	-2.801	-2.681	-2.572	-2.473	-2.383	-2.301
IRR														0%	1%	2%	3%	3%	4%	4%	5%
Price scenario 3:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423	423
NPV	-7.000	-6.615	-6.266	-5.948	-5.659	-5.396	-5.158	-4.941	-4.743	-4.564	-4.401	-4.253	-4.118	-3.995	-3.884	-3.783	-3.691	-3.607	-3.531	-3.462	-3.399
IRR																	0%	0%	1%	1%	2%
Price scenario 4:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922	922
NPV	-7.000	-6.162	-5.400	-4.707	-4.077	-3.505	-2.984	-2.511	-2.081	-1.690	-1.335	-1.012	-718	-451	-208	13	213	396	562	712	850
IRR									1%	4%	5%	7%	8%	9%	9%	10%	11%	11%	11%	12%	12%
Price scenario 5:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798	798
NPV	-7.000	-6.275	-5.615	-5.015	-4.470	-3.975	-3.525	-3.115	-2.743	-2.404	-2.097	-1.817	-1.563	-1.332	-1.121	-930	-757	-599	-455	-325	-206
IRR										1%	2%	4%	5%	6%	7%	8%	8%	9%	9%	9%	10%
Price scenario 6:																					
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash flow	-7.000	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669	669
NPV	-7.000	-6.392	-5.839	-5.336	-4.879	-4.464	-4.086	-3.743	-3.431	-3.147	-2.889	-2.655	-2.442	-2.248	-2.072	-1.912	-1.766	-1.634	-1.513	-1.404	-1.304
IRR												1%	2%	3%	4%	5%	5%	6%	6%	7%	7%

Appendix 9. Emission reduction

Wetfish trawlers: annual emission of pollutants, expressed in tonnes.

Ottó N. Þorláksson RE-203					
	Fuel	SOx	NOx	PM	CO ₂
Before:	MGO	5,7	135	2,8	8.576
After:	MGO	2,9	68	1,4	4.332
	LNG	0,0	13	0,5	3.049
	Total: MGO+LNG	2,9	81	1,9	7.381
Reduction:		49%	40%	33%	14%

Ásbjörn RE-50					
	Fuel	SOx	NOx	PM	CO ₂
Before:	MGO	5,3	125	2,6	7.945
After:	MGO	2,6	62	1,3	3.971
	LNG	0,0	13	0,4	2.859
	Total: MGO+LNG	2,6	75	1,8	6.830
Reduction:		50%	40%	33%	14%

Pelagic vessels:

Ingunn AK-150					
	Fuel	SOx	NOx	PM	CO ₂
Before:	MGO	8,6	204	4,3	12.970
After:	MGO	2,1	51	1,1	3.246
	LNG	0,0	31	1,1	6.991
	Total: MGO+LNG	2,1	82	2,1	10.236
Reduction:		75%	60%	50%	21%

Faxi RE-9					
	Fuel	SOx	NOx	PM	CO ₂
Before:	MGO	7,2	171	3,6	10.896
After:	MGO	2,0	47	1,0	3.022
	LNG	0,0	25	0,9	5.661
	Total: MGO+LNG	2,0	72	1,9	8.683
Reduction:		72%	58%	48%	20%

Lundey NS-14					
	Fuel	SOx	NOx	PM	CO ₂
Before:	MGO	8,0	189	4,0	12.030
After:	MGO	2,4	56	1,2	3.556
	LNG	0,0	27	0,9	6.093
	Total: MGO+LNG	2,4	83	2,1	9.649
Reduction:		70%	56%	47%	20%

Appendix 10. E-mails

10.1 Operation at high engine loads

E-mail conversation with Loftur B. Gíslson Product Manager at HB Grandi.

Guðrún Jóna Jónsdóttir

Til: loftur@hbgrandi.is

15. febrúar 2013 09:34

Sæll Loftur og takk kærlega fyrir að aðstoða mig með þessar upplýsingar. Mig langar til að vita hvort að þið eigið einhverjar upplýsingar um hvernig orkumynstrið sé í hefðbundnum túr ísfiskiskipa sem og uppsjávarskipanna. Hvenar í túrnum eru skipin að nýta fullt vélarafl? og hversu mikið hlutfall er það af heildar túrnum?

Málið er að ég er að kanna það að skipta vélunum yfir í dual-fuel LNG vélar þar sem skipið myndi keyra aðallega á LNG (liquefied natural gas) í "gas mode" en myndi nota olíu í "diesel mode" sem back-up, þar sem talað er um að keyrsla á gasi geti ekki afkastað nema 80% af heildar vélarafli skipsins og því þyrfti að skipta yfir í olíu ef meira en 80% vélarafl þarf. Ég þarf einhvern vegin að áætla gróflega hversu hátt hlutfall af heildar túr er skipið að þurfa að fara yfir 80% vélarafl.

Bestu kveðjur

Guðrún Jóna Jónsdóttir
Nemandi í Framkvæmdarstjórnun
Háskólinn í Reykjavík

Loftur Bjarni Gíslason [loftur@hbgrandi.is]



Til: Guðrún Jóna Jónsdóttir

15. febrúar 2013 10:1

- Þú svaraðir þann 15.2.2013 12:50.

Sæl Guðrún
Þetta kom frá Kalla sem sér um vélarnar og viðhald á uppsjávarskipunum og Sturlaugi H Böðvarssyni.

Sæll.
Þetta er "tricky" spurning.
Menn vilja alltaf hafa aðgang að sem mestu vélarafli. Þetta er að sjálfsögðu tengt því hver sigld stefna er miðað við veður. Því verra veður, því meiri olía, ef siglt / togað er á móti veðri.
Varðandi ís-fiskarana, þá er ekki mikið umfram vélarafl í þeim skipum, þurfa helst að hafa aðgang að sem mestu. Sumrin og sá hluti vetrarins sem er með besta veðrið væri þá helst sá tími sem hægt væri að nýta orku sem krefðist ekki fullra afkasta vélanna, auk þess sem unnt væri að sættast á minni orku þegar skipin eru á siglingu (ekki veiðum). Skot út í loftið, gæti verið eitthvað nálægt 70% af tímanum sem hægt væri að láta 80% afl duga.

Varðandi uppsjávar skipin er þetta svoldið annað. Þar eru skipin 50% af tímanum á keyrslu, til eða frá veiðisvæðum, auk þess sem veiðarnar eru ekki mjög orkufrekar nema þegar verið er á kolmunnaveiðum. Þar væri trúlega hægt að seigja að 90% tímans væri hægt að sættast á að hafa einungis 80% vélaraflsins úr að spila. Samt er það alltaf spurning. Sé t.d. núna að Lundey er að sigla á 14 til 15 sjóm hraða á leið á miðin sem þíðir að hann er að nota verulegann hluta af vélaraflinu. Hún nær með þessu 75% af deginum í dag á miðunum en núna er eingöngu veiði á daginn. Ef hann keyrði hagkvæmustu ferð, kæmi hann ekki á miðin fyr en seinnipartinn og fengi þá engann afla fyr en á morgunn. Á sama hátt var Ingunn eingögnu á 10 sjóm, þegar hún sigldi í land í gær. Þá var ekki reiknað með að hún kæmist í löndun um leið og hún kæmi í land og lá því ekkert á.

Ef unnt er að skipta fyrirvaralítið af gasinu yfir á diesel og aftur til baka, væri jafnvel hægt að hafa gasið enn meira en ég er að spá hér.
Kv. Kalli.

Kveðja Loftur Bjarni Gíslason
Framleiðslustjóri ísfiskiskipa

10.2 Operation at low engine loads

E-mail conversation with Karl Sigurjónsson vessel maintenance manager at HB Grandi.

-----Original Message-----

From: Guðrún Jóna Jónsdóttir [<mailto:gudrunj11@ru.is>]

Sent: 19. mars 2013 12:36

To: Karl Sigurjónsson

Subject: vélarafl

Sæll Karl

ég heiti Guðrún og hef verið í sambandi við hann Loft með upplýsingar fyrir meistararitgerð mína um að skipta orkugjafa fiskiskipa yfir í LNG.

Þú svaraðir spurningu um daginn um þann tíma sem ísfiskiskipin og uppsjávarskipin væru hlutfallslega að nýta meira en 80% vélarafl í túr og er svar þitt hér fyrir neðan. Ákvað því að senda þér þessa fyrirspurn beint.

Mig langar til að spyrja um það sama með lágt vélarafl, minna en 15%. Hversu hátt hlutfall af túr telur þú að skipin uppsjávar og ísfiskiskip séu að nota minna en 15% vélarafl? er það ekki bara rétt á meðan þeir eru að sigla úr höfn og vélarnar að hitna? en samkvæmt framleiðanda dual-fuel véla þarf að vera á diesel-mode þega vélarafl undir 15% er notað sem og vélarafl herra en 80%. Fyrirvaralaust er hægt að skipta á milli diesel-mode og gas-mode.

Bestu kveðjur

Frá: Karl Sigurjónsson [karls@hbgrandi.is]

Sent: 19. mars 2013 15:30

Til: Guðrún Jóna Jónsdóttir

Efni: RE: vélarafl

Sæl Guðrún.

Þessu er fljót svarað varðandi ísfiskarana og togara almennt, þeir eru nánast aldrei með minna en 15% af vélaraflinu í notkun, a.m.k. ekki þau skip sem framleiða rafmagn á aðalvélinni. Það er eins og þú bendir á nánast eingöngu fyrst eftir gangsetningu og svo fyrir stöðvun á vélunum, í lok veiðiferðar. Jafnvel þó skipin lóni einungis uppí veður og vind, á orkunotkunin að vera yfir 15%.

Það sama á við um uppsjávar skipin að mestu leiti. Þó geta þau stundum verið á reki hluta af sólarhringnum vegna þess að viðkomandi fisktegund veiðist ekki allan sólarhringinn. Stundum þarf aðalvélin samt að ganga vegna kælingar á afla. Ef ekki er um meiri orkunotkun að ræða getur það verið undir þessum 15%. En ef skipin eru að lóna um og leita að líklegum lóðningum, þá er notkunin væntanlega strax komin yfir 15%. Held það sé nánast óhætt að horfa framhjá þessari lágmarks notkun (notkunarleysi) í annan tíma, það er svo hverfandi lítið.

Kveðia / Best regards

10.3 MARPOL Annex VI.

E-mail conversation with Hugi Ólafsson at the Ministry of the Environment and Natural Resources, Department of Oceans, Water and Climate regarding why Iceland has not accepted Annex VI.

hugi.olafsson@uar.is



Til: Guðrún Jóna Jónsdóttir

18. febrúar 2013 1

- Þú svaraðir þann 18.2.2013 14:01.
- Stöðuvísir fyrir eftirfylgni. Lokið 19. febrúar 2013.

Date: 15.02.2013 13:15

Subject: Útblástur skipa

Sæll

Ég heiti Guðrún Jóna og er meistaranemi í Háskólanum í Reykjavík. Ég er að vinna að meistararitgerð minni þessa önn þar sem ég er að kanna hagkvæmni þess að skipta orkugjafa íslenskra skipa yfir í LNG (fljótandi jarðgas), sem er bæði ódýrara eldsneyti og umhverfisvænna en olía.

Það kom mér á óvart þegar ég fór að skoða alþjóðasamning MARPOL sem Ísland er aðild að, að viðauki VI um Reglur um loftmengun frá skipum hafi verið undanskilin. Ég átti fund með Sigurrós hjá Umhverfisstofnun í morgun sem benti mér á að hafa samband við þig. Veist þú hvers vegna þessi viðauki hafi ekki verið samþykktur í upphafi og ef stefnt er á að samþykka hann í náinni framtíð, hvernig þau mál standi í dag?

Bestu kveðjur

Guðrún Jóna Jónsdóttir
Nemandi í Framkvæmdarstjórnun
Háskólinn í Reykjavík

hugi.olafsson@uar.is



Til: Guðrún Jóna Jónsdóttir

18. febrúar 2013 13:51

- Þú svaraðir þann 18.2.2013 14:01.
- Stöðuvísir fyrir eftirfylgni. Lokið 19. febrúar 2013.

Sæl,

Þessi viðauki hefur ekki verið fullgiltur, en það þýðir ekki að hann hafi ekki verið samþykktur. Ýmsum alþjóðasamningum er lítið sinnt af Íslands hálfu, vegna takmarkaðra fjármuna, þ.á m. MARPOL, en að auki eru mörg ákvæði þeirra innleidd síðar í gegnum EES-samninginn, þótt æskilegra sé að Ísland fullgildi þá jafnframt viðkomandi alþjóðasamning, bókun eða viðauka. Fullgilding bókana og viðauka er þungur ferill, sem kallar á greiningarvinnu og þýðingar og það biða nokkrir slíkir eftir afgreiðslu, þ.á m. varðandi MARPOL. Bæði ráðuneytið og Umhverfisstofnun, sem sér um MARPOL f hönd ráðuneytisins, hafa nýlega farið í gegnum endurskipulagningu og erum við að fara yfir málefni hafsins þessa vikuna og þ.á m. hvernig alþjóðasamningum er sinnt. Það er vilji til að reyna að ýta nokkrum viðaukum og bókunum í gegnum fullgildingarferli á þessu ári, en það er utanríkisráðuneytið sem sér formlega um slíkt eftir grunnvinnu hjá viðkomandi fagráðuneyti og stofnun. Varðandi spurninguna hvort reglur hér um loftmengun frá skipum séu sambærilegar við önnur Evrópuríki þótt viðaukinn sé ekki fullgiltur þyrfti ég að vísa á sérfræðinga hjá UST.

M kveðju,
Hugi

Hugi Ólafsson, skrifstofustjóri / Director

Umhverfis- og auðlindaráðuneytið, skrifstofa hafs, vatns og loftslags

Ministry for the Environment and Natural Resources, Department of Oceans, Water and Climate

10.4 MGO cost from N1

Magnús Ásgeirsson [magnus@n1.is]



Til: [Guðrún Jóna Jónsdóttir](#)

Viðhengi: [Guðrún Jóna.xls \(19 KB\)](#) [Opna í vafra]

14. febrúar 2013 13:31

• Þú svaraðir þann 14.2.2013 16:31.

2010	Flotaolía	2011	Flotaolía	2012	Flotaolía
janúar	95,22	janúar	108,69	janúar	137,38
febrúar	99,12	febrúar	114,11	febrúar	142,76
mars	104,13	mars	125,13	mars	150,14
apríl	107,54	apríl	129,57	apríl	151,89
maí	107,38	maí	126,28	maí	143,44
júní	101,94	júní	125,50	júní	134,10
júlí	99,60	júlí	128,96	júlí	134,78
ágúst	99,60	ágúst	129,91	ágúst	140,63
september	98,84	september	129,08	september	147,92
október	97,67	október	126,62	október	149,05
nóvember	100,54	nóvember	130,87	nóvember	147,67
desember	106,29	desember	132,43	desember	146,04
Meðaltal	101,49	Meðaltal	125,59	Meðaltal	143,82

10.5. Engine conversion cost

E-main conversation with Johan Hansten Sales Director at Wartsila.

my name is Gudrun and I am a student at the University of Reykjavík.

I am writing my master thesis this semester and I am investigating the feasibility of the Icelandic fishing fleet changing their fuel to LNG.

My study will be about a wetfish trawler of GRT:880, Length: 57m, Beam: 10,3m, Depth: 7,3m, with a diesel engine running on MGO.

I was hoping I could get some information from you about how much it would cost to change a ship like this to Dual-fuel engine running on both MGO and LNG.

I also found an article saying that it would add 10-20% to the investment cost for a new LNG ship compared to regular ships, is that true? Another thing I would like to know, is maintenance cost for a ship running on LNG more, less or the same as a ship running on oil as MGO?

Hope you can help me with this information

Best regards

Reply from Wartsila 8.february 2013:

Dear Gudrun,

May you please inform us some more info on the existing fleet?

What kind of machinery is now installed, medium or high speed engines? What is installed power etc.

It is true that initial investment cost (Capex) is higher than for regular ships, as you have 2 fuel system (gas & diesel) instead of 1 only (diesel).

Maintenance cost for LNG and MGO is expected to be more or less same, but you have to keep in mind that operating cost for LNG will be considerable lower as LNG is cheaper than MGO.

Best regards,

Johan Hansten

The types of engine the ships have are:

One has 2000 model Wartsila32 engine, typ 9L32, 4500 Kw.

The other has 1999 model Wartsila 32 engine, typ 12V32, 4920 Kw.

can you give me a price estimate on how much it would cost to convert these engines to dual-fuel engines that can run on LNG?

Best regards

Guðrún Jóna Jónsdóttir

Frá: johan.hansten@wartsila.com [johan.hansten@wartsila.com]
Sent: 4. mars 2013 14:22
Til: Guðrún Jóna Jónsdóttir
Efni: FW: Information

Dear Gudrun,

You have put forward a quite complex question and I can give only a very general response.

The engine conversion is maybe in the region of 1 - 1,5 MEUR. Depending a bit on where and how it is done. In addition you need also to need a complete gas system with tanks etc and all yard work, so in total we talk about an estimated cost of 5-7 MEUR

Best regards,
Johan Hansten

10.6 Cost of a new ship

E-mail conversation with Karl Lúðvíksson a Ship Engineer at NAVIS.

-----Original Message-----

From: Guðrún Jóna Jónsdóttir [<mailto:gudrunj11@ru.is>]

Sent: 17. mars 2013 13:34

To: Karl Lúðvíksson

Subject: SV: Verð á skipum

Sæll Karl

Þar sem ég er að skirfa meistararitgerð og mun nota þau viðmiðunarverð sem þú gafst mér upp um daginn varðandi verð á ísfiskitogara og uppsjávarskip þyrfti ég að hafa staðfestingu á því hér í pósti til að geta vitnað í.

Þau viðmiðunarverð sem þú gafst mér voru:

Ísfiskitogari 50m lengd*12m breidd*7,6m dýpt = 2,5-2,7 milljarðar ISK

Uppsjávarskip 67m lengd*15m breidd*8,5m dýpt = 4,5-5,2 milljarðar ISK Þetta er verð án VSK og er á veiðarfæra.

Eins sagðir þú í símanum að verðin færu mikið eftir því hvar þau væru smíðuð og þessi verð séu byggð á verðum sem útgerðir í vestur-evrópu séu að borga fyrir sín skip. Skrokkur sé byggður í láglaunalöndum og síðan kláruð í evrópu, t.d Noregi. Verð á skipum með frystigetum eru í efri kantinum.

Gætir þú staðfest þetta við mig

Takk kærlega fyrir aðstoðina

Bestu kveðjur

Guðrún Jóna Jónsdóttir

Nemandi í Framkvæmdarstjórnun

Háskólinn í Reykjavík

Karl Lúðvíksson [kl@navis.is]



Til: [Guðrún Jóna Jónsdóttir](#)

19. mars 2013 13

- Þú svaraðir þann 19.3.2013 14:18.

Sæl Guðrún,

Ég get staðfest að þetta eru tölurnar sem ég gaf þér miðað við gengi þess dags þegar upplýsingarnar voru gefnar. Ég myndi áætla að lægri tölurnar miðuðust við að skipin væru að öllu leyti smíðuð í austur-evrópu, t.d. króatíu en að hærri tölurnar væru einhverskonar meðalverð. Sennilega þyrfti að bæta 10-15% við þær ef bolirnir væru smíðaðir í láglaunalandi og skipin kláruð í vestur-evrópu. Nokkuð fer líka eftir því hversu mikill véla- og tækjabúnaður er í skipunum. Þetta eru tölur byggðar á samningsverði nýsmíða sem afhentar hafa verið á þessu og síðasta ári. Meðan aðrar upplýsingar eru ekki fyrir hendi er þetta það skásta sem ég get látið þér í té.

M.kv.

Navis ehf.

Karl Lúðvíksson

10.7 Acceptable Discount Rate

E-mail conversation with the HB Grandi Fleet Manager about the acceptable discount rate of investments.

-----Original Message-----

From: Guðrún Jóna Jónsdóttir [<mailto:gudrunj11@ru.is>]

Sent: 19. mars 2013 12:10

To: Rúnar Þór Stefánsson

Subject: Ávöxtunarkrafa

Sæll Rúnar

ég var búin að senda þessa fyrirspurn á Loft en hef ekkert svar fengið spurning hvort þú hafir svarið :)

Þar sem ég er að reikna Núvirði á fjárfestingu við að breyta skipum yfir í LNG og eins viðbótarfjárfestingu á nýjum LNG skipum miðað við venjuleg skip langar mig að forvitnast hvað ykkur finnst ásættanleg ávöxtunarkrafa þegar þið fjárfestið?

Kveðja

Guðrún Jóna Jónsdóttir

Nemandi í Framkvæmdarstjórnun

Háskólinn í Reykjavík

Blessuð

Í ljósi aukinnar gjalddöku á greinina þurfum við að gera auknar kröfur um framlegð fjárfestinga til að geta staðið undir ávöxtunarkröfunni, sem við metum í hverju verkefni fyrir sig. Í tilfalli nýsmíðar á skipi er eðlilegt að gera ráð fyrir ávöxtunarkröfu sem er að lágmarki 10%, en taka þarf tillit til margra þátta, áhættu ofl., þannig að talan sem ég set fram er ekki endanleg niðurstaða.

Kveðja

Rúnar Þór Stefánsson

Útgerðarstjóri

10.8 Size of existing fuel tanks and expected lifetime of ships

E-mail conversation with Loftur B. Gíslason Product Manager at HB Grandi.

From: Guðrún Jóna Jónsdóttir <gudrunj11@ru.is>
Date: 6. mars 2013 12:28:09 GMT
To: Loftur Bjarni Gíslason <loftur@hbgrandi.is>
Subject: Tanka rými

Sæll Loftur

Getur þú sagt mér hversu mikið magn af olíu ísfiskiskipin og uppsjávarskipin geta tekið, þ.e hversu stórir eldsneytistankar eru um borð?

Eins langar mig að spurja út í viðhaldskostnaðinn sem þú sendir mér, en sumt er gefið upp með skatt og annað án skatt, fáist þið ekki allan skatt endurgreiddann?

Ég sendi þér spurningu um daginn varðandi líftíma skipanna, veistu eitthvað hvað mætti áætla að líftími þeirra væri?

Takk enn og aftur með alla þessa hjálp, þetta er að verða komið hjá mér :)

Bestu kveðjur

From: Karl Sigurjónsson <karls@hbgrandi.is>
Date: 6. mars 2013 15:01:55 GMT
To: Loftur Bjarni Gíslason <loftur@hbgrandi.is>, Gísli Jónmundsson <gisli@hbgrandi.is>
Subject: RE: Tanka rými

Sæll,

Sturlaugur: tankapláss um 110.000 L. Áætlaður líftími án endurbýggingar: 10-15 ár. Með endurbýggingu 25 ár. J

Faxi: tankapláss um 340.000 L. Áætlaður líftími án endurbýggingar: 10-15 ár. Með endurbýggingu 25 ár. J

Ingunn: tankapláss um 400.000 L. Áætlaður líftími án endurbýggingar: 10-15 ár. Með endurbýggingu 25 ár. J

Lundey: tankapláss um 280.000 L. Áætlaður líftími án endurbýggingar: 10-15 ár. Með endurbýggingu 25 ár. J

Víkingur: tankapláss um 110.000 L. Áætlaður líftími án endurbýggingar: 10-15 ár. Með endurbýggingu 25 ár. J

Skipin eru í stöðugu viðhaldi og endurnýjun á búnaði eftir þörfum. Leifi mér því að segja að þau geti dugað í 10-15 ár í viðbót. Ef við höldum svipuðum standard í viðhaldinu, getum við vonandi sagt eftir 10 ár, að skipin eigi enn eftir 10 til 15 ár í endingu, miðað við að þau sleppi áfalla lítið úr glímunni við Ægi.

Hinsvegar getur ný tækni eða þróun í vinnslu/veiðum valdið því að skipin úrelast, líkt og hefur gerst með Víking. Hann er samt í ágætis ástandi en hentar ekki lengur á uppsjávarveiðar þar sem krafa er um klæðan afla eða veiðar stundaðar með trolli og er hann því eingöngu notaður á loðnuveiðar með nót.

Lundey er hinsvegar endurbýggð með tilliti til breyttra aðstæðna og setti hana öflugur togbúnað, smíðaður nýr framendi með kælitonkum og er hún því útbúinn á svipaðann hátt og Faxi + Ingunn. Faxi og Ingunn eru hinsvegar búnar mun öflugra kælikerfi en Lundey. Þar kemur hugsanlega að einhverju leiti fram munurinn á endurbýggingu og nýsmíði, þó svo að Faxinn hafi farið í verulega endurnýjun um 2000.

Kv. Kalli.

From: Gísli Jónmundsson <gisli@hbgrandi.is>
Date: 6. mars 2013 16:16:09 GMT
To: Loftur Bjarni Gíslason <loftur@hbgrandi.is>
Subject: RE: Tanka rými

Sæll Loftur

Ásbjörn Re

Ottó N. Þorláksson Re

forðageymar eldsneytisoliu 144 m3

forðageymar eldsneytisoliu 180 m3
