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Development of liquid natural gas bunkering infrastructure in South African ports : a feasibility study for port of Cape Town and port of Durban

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WORLD MARITIME UNIVERSITY
Malmö, Sweden

DEVELOPMENT OF LIQUID NATURAL GAS BUNKERING INFRASTRUCTURE IN SOUTH AFRICAN PORTS

A Feasibility Study for Port of Cape Town and Port of Durban

By

MABOTE ELLIOT MOTSOAHOLE
South Africa

A dissertation submitted to the World Maritime University in partial
Fulfilment of the requirements for the award of the degree of

MASTER OF SCIENCE
In
MARITIME AFFAIRS

(MARINE SAFETY AND ENVIRONMENTAL ADMINISTRATION)

2014

DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **Development of Liquid Natural Gas Bunkering Infrastructure in South Africa: A Feasibility Study for Port of Cape Town and Port of Durban.**

Degree: **MSc**

In recent years, the use of LNG as marine fuel has been high on the agenda of the shipping industry following the introduction of increasingly stricter air emissions legislation by the International Maritime Organization (IMO) and financial considerations. This has triggered major developments with the introduction of LNG fuelled vessels which many experts anticipate to increase further, thereby resulting in LNG marine fuel demand.

However, the supply of natural gas as LNG marine fuel is presently constrained by lack of bunkering infrastructure due to intensive capital requirements and volume sensitivity. Similarly, South Africa does not have LNG marine fuel bunkering infrastructure despite the abundance of natural gas from potential suppliers like Mozambique and Tanzania in close proximity and its location in one of the main shipping routes. The viability of LNG bunkering infrastructure in South Africa depends on a number of critical factors in addition to volume demand and financial aspects. LNG is a combustible cryogenic liquid and as such presents safety hazards with potential to cause severe consequences. On the other hand, LNG is an attractive alternative clean source of energy with significant environmental benefits as marine fuel.

This research provides a general overview of the global LNG market and establishes potential demand as marine fuel in South Africa. Subsequently, the study identifies existing natural gas infrastructure and government plans for future developments. Based on the projected development plans, a bunkering supply chain solution for LNG marine fuel is proposed together with the infrastructure requirements and the main ports to serve as bunker hubs. An investment analysis is then undertaken for the proposed supply chain which takes into account financial, safety, environment and externality costs and makes conclusions thereof based on the outcome.

KEY WORDS: MARPOL Annex VI, LNG, bunkering, infrastructure, investment analysis, ship emissions, externalities of air pollution, safety, environment.

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AE	Auxiliary Engine
ALARP	As Low As Reasonably Practical
CCGT	Closed Cycle Gas Turbine
CO_2	Carbon Dioxides
DEDT	Department of Economic Development and Tourism
DMA	Danish Maritime Authority
DME	Department of Minerals and Energy
DOE	Department of Energy
EUR	Euro
ECA	Emission Control Area
ESD	Emergency Shut Down
GHG	Greenhouse Gases
GTL	Gas to Liquids
FSRU	Floating Storage and Regasification Unit
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
ISO	International Standards Organization
IMDG	International Maritime Dangerous Goods
LNG	Liquefied Natural Gas
LS MGO	Low Sulphur MGO (0.1% S)
LTDF	Long Term Development Framework
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil

MGO	Marine Gas Oil
MTPA	Metric Tonnes Per Annum
NO_x	Nitrogen Oxides
NPV	Net Present Value
ODS	Ozone Depleting Substances
OECD	Organisation for Economic Cooperation and Development
PM	Particular Matters
RPT	Rapid Phase Transformation
RO	Residual Oil
ROMPCO	Republic of Mozambique Pipeline Company
SCR	Selective Catalytic Reduction
SMS	Safety Management System
SOP	Standard Operating Procedure
SO_x	Sulphur oxides
TNPA	Transnet National Ports Authority
USD	United States Dollar
USEIA	United State Energy Information Administration
VOC	Volatile Organic Compounds
VTS	Vessel Traffic Service
WEC	World Energy Council

CHAPTER 1 – INTRODUCTION

1.1 Background of Study

Natural gas is receiving attention as a potential clean energy alternative to traditional transport fuels. As a result, the use of natural gas has been growing steadily in many sectors including industrial initiatives, public investment, emerging research projects, new government policies and incentives etc. (Lowell, Wang & Lutsey, 2013, p5). Likewise, the shipping industry is also showing steady growth in pursuing natural gas in its form as Liquid Natural Gas (LNG) for an alternative marine fuel. However, in recent years the use of LNG as marine fuel has been accelerated following the introduction of increasingly stricter air emissions legislation by the International Maritime Organization (IMO) and financial considerations. The use of LNG as marine fuel is one of the key strategies for compliance with regulatory requirements (World Energy Council [WEC], 2013, p15). Moreover, many governments have adopted environmental policies and regulations to reduce greenhouse gas (GHG) emissions and thereby support initiatives like LNG fuel.

The shipping industry has since seen major development with the introduction of LNG fuelled vessels which many experts are projecting further increase, thereby resulting in LNG marine fuel demand (Aagesen, 2012, p7). However, the supply of LNG marine fuel is constrained by a number of challenges including lack of bunkering infrastructure, regulatory framework to maintain current safety record without hampering infrastructure development and LNG availability. The development of LNG bunkering infrastructure faces a typical “chicken and egg” dilemma, where ship owners are reluctant to convert to LNG until there is guaranteed supply while, on the other hand, suppliers also need guaranteed demand before investing in bunkering infrastructure (Semolinos, Olsen & Giacosa, 2011).

Similarly, South Africa (SA) does not have LNG marine fuel bunkering infrastructure despite the abundance of natural gas from potential suppliers like Mozambique and Tanzania in close proximity. In addition, South Africa is geographically well positioned within one of the main shipping routes in the Cape of Good Hope and has an opportunity to take advantage of vessel traffic in the region. On the contrary, it has been widely reported by the International Bunker Industry Association (IBIA) and industry stakeholders that the current bunker market for traditional fuel has decreased significantly over the years due to a number of reasons including bunker price and reliability of supply. Therefore, this study will seek to assess viability of supplying LNG as an alternative cost effective marine fuel through the development of LNG bunkering infrastructure in South Africa.

1.2 Problem Statement

The Department of Energy [DOE] (2013, p29) has raised concerns that transportation in South Africa is heavily dependent on petroleum liquids thereby making it vulnerable to the availability and cost of oil. In addition, the country depends on energy generated from coal to sustain key economic activities. The challenge with current energy sources is that they contribute significantly to GHG emissions and climate change thereby posing health hazards to humans and negative environmental impacts. The price of petroleum liquids is volatile and has increased substantially over the years thereby increasing transportation costs.

Natural gas presents an alternative energy source to diversify the country's energy mix and fuel for transportation. There is limited natural gas infrastructure in SA and none available to enable alternative marine fuel energy supply in the form of LNG. According to Transnet National Ports Authority (TNPA) as quoted by Buthelezi (2014), the investment in LNG infrastructure has been previously avoided in ports due to the associated safety hazards. LNG is odorless, colorless, noncorrosive, and nontoxic, but flammable under certain well known conditions and it can cause severe consequences (SIGTTO, 2003, p3).

1.3 Research Objectives

The main objective of this study is to assess viability of supplying LNG as an alternative cost effective marine fuel through the development of LNG bunkering infrastructure in South Africa. The main objective was unpacked as follows for further analysis in the study:

a) Identify key drivers for the adoption of LNG as alternative energy source for reduction of ship emissions within the South African context;
b) Identify current and future plans for the development of LNG infrastructure;
c) Establish LNG bunkering supply chain aligned with the proposed national development plans;
d) Estimate a rational investment cost for the development LNG bunkering infrastructure within the identified bunker ports;
e) Identify safety aspects associated with handling of LNG and potential environmental issues.

1.4 Research Questions

In achieving the above mentioned objectives, the study will strive to answer the following questions:

a) What is the current and potential future demand for LNG marine fuel from the shipping industry?
b) Is the development of LNG bunkering infrastructure viable in South African ports and what is the solution for a suitable supply chain?
c) What are the key environmental and safety issues related to LNG operations?

1.5 Methodology and Limitations

The research methodology was underpinned by literature review of previous studies and similar case studies. In addition, quantitative analysis was conducted to establish the potential LNG marine fuel demand in South Africa based on vessel statistics sourced from TNPA website. The proposed LNG supply chain was built around LNG infrastructure scenarios from Transnet Long-term Development Framework of 2013 and Western Cape pre-feasibility study for importation of natural gas. Net Present Value was used as a preferred method in appraising viability for the proposed bunkering infrastructure options.

Safety assessment was conducted through literature review by identifying potential hazards and risk control measures for key bunkering activities. This was followed by screening of environmental issues to determine if there are any potential environmental flaws. In addition, environmental gains and externality costs were assessed based on the estimated ship emissions within the study areas and a number of assumptions were made for the analysis.

The limitations of the study have been defined as follows;

- The scope of this study was only limited to two out of eight TNPA ports which were identified as bunkering hubs;
- Investment analysis cover only the necessary infrastructure required to establish LNG bunker facility, and does not include any infrastructure required on board of LNG fuelled ships.

- Financial values are largely based on estimates and theoretical assumptions;
- Safety assessment is based on literature review and it is more generic as it is expected that a specific safety risk assessment should be conducted taking into consideration unique conditions to each port;
- The study is only limited to LNG bunkering operations and exclude details for the development of LNG import terminals.

1.6 Outline of the Study

This study is structured as follows:

- Chapter 1 serves as the introduction and includes background to the research, problem statement, research objectives and questions together with the methodology and study limitations.
- Chapter 2 provides literature review from different sources with focus on the key drivers for natural gas and LNG as marine fuel.
- Chapter 3 provides an overview of current natural gas infrastructure from the African level to South Africa's planned future LNG import infrastructure and the proposed supply chain.
- Chapter 4 includes feasibility assessment for the development of LNG bunkering infrastructure from an economical, safety, externalities and environmental point of view. This chapter also contains an investment analysis for the proposed infrastructure in Port of Cape Town and Durban based on the Net Present Value method.
- Chapter 5 concludes the study with a summary and recommendations for a way forward.

CHAPTER 2 - LNG OVERVIEW

2.1 What is LNG?

LNG is a natural gas that has been cooled to the point that it condenses to a liquid, which occurs at a temperature of approximately –162°C at atmospheric pressure. Natural gas is converted into liquid form through liquefaction process to enable transportation over long distances especially where distribution pipelines are not feasible or other constraints exist. Once natural gas is converted to LNG, its volume is reduced by a factor of 610 and it allows storage and transportation in big volumes (US Energy Information Administration [USEIA], 2003, p4; Foss, 2007, p8).

Large volumes create an opportunity to benefit from economies of scale for transportation of LNG by ships with super insulated tanks. Upon arrival at receiving a facility, it may be stored or regasified to turn back the liquid into a gas for distribution through a pipeline to customers. LNG may also be transported in special tanker trucks to small facilities where it is stored and regasified as needed during peak periods (US DOE, 2005, p3). Viability of LNG transportation by ship in comparison to a pipeline is when the distance between the source and consumer is around 2000 kilometres by sea and around 3,800 kilometres over land (USEIA, 2003, p4).

Natural gas comprises mainly methane (CH_4), which also makes up approximately 85 to 95% of LNG, together with ethane, propane, butane, and nitrogen in smaller percentages (Figure 2.1) (US DOE, 2005, p3; Vanderbroek & Berghmans, 2012, p1). Other gases such as carbon dioxide (CO_2), nitrogen (N_2), oxygen (O_2), hydrogen sulphide (H_2S) and water are also often present. At the liquefaction process all these gases and heavier hydrocarbons are removed. The composition of natural gas also varies from one field location to another (Verbeek et al., 2011, p14; Vanderbroek & Berghmans, 2012, p1). Further, like methane, LNG is odorless, colorless, noncorrosive, and nontoxic (US DOE, 2005, p3), but flammable under certain well known conditions (SIGTTO, 2003, p3). As a part of safety engineering, all LNG facilities are designed to prevent fires and contain the LNG in the event of a spill (USEIA, 2003, p3).

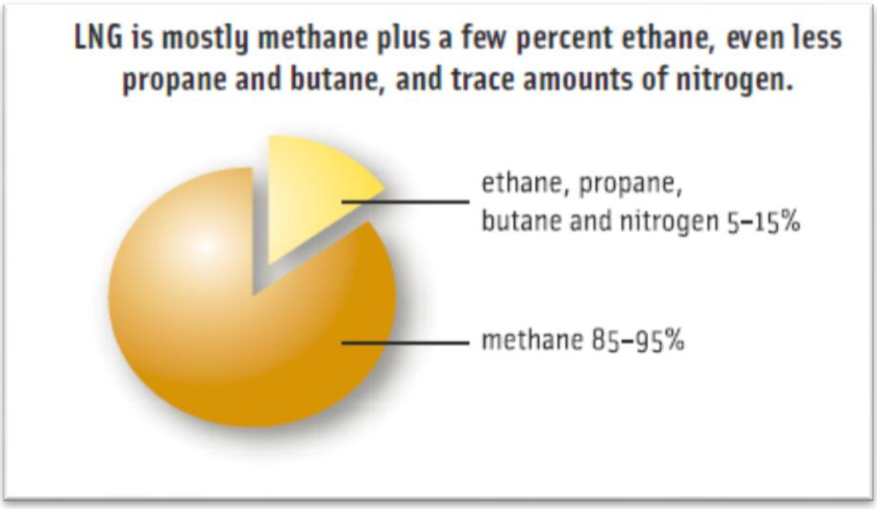


Figure 2.1: LNG Composition (Source: US DOE, 2005)

2.2 Why Natural Gas/LNG?

Over the years, the source of fuel energy has evolved from being primarily coal to a diverse mix of gas, nuclear and coal. Natural gas, as a fuel has numerous advantages not only limited to its clean burning characteristics and these are highlighted below together with some disadvantages.

2.2.1 Advantages

Power generation – Natural gas is an attractive alternative fuel for new power generation plants because of relatively low capital costs and the favorable heat rates for natural gas generation (USEIA, 2013). For instance, Combined Cycle Gas Turbine (CCTG) is a proven power generation technology that uses natural gas as a source, thereby allowing it to be environmentally friendly. It is regarded as a safe, clean, efficient form of power generation as the plant produces electricity through the use of gas turbines. CCGT power plants also have greater thermal efficiency than other generation technology options based on conventional fossil fuel (Council for Scientific and Industrial Research [CSIR], 2004, p3; Environmental Resource Management [ERM], 2005, p2).

Availability – According to several literature sources, it has been widely accepted that there is an abundance of natural gas reserves worldwide with diversified availability to ensure security of supply (Bhattacharyya, 2011, p353; McGill, Remley & Winther, 2013, p40). Furthermore, in comparison to other renewable energy sources like solar and wind, natural gas is consistently available 24 hrs/365 days as it does not depend on weather conditions.

Environmental Benefits: Natural gas provides an alternative form of energy that is clean and more efficient compared to other energy sources. It has lower carbon intensity with no particulate matter and less NOx than other fossil fuels (McGill et al, 2013, p41). In addition, most of the sulphur is removed during the liquefaction process, thereby resulting in a negligible amount of SO_2 being released during combustion of regasified LNG (ERM, 2005, p2). Bhattacharyya (2011, p353) indicated that natural gas emits 30% less CO_2 compared to oil and almost 70% less compared to coal for an equivalent amount of energy. This makes it an attractive fuel source in countries where governments are implementing policies to reduce greenhouse gas emissions (USEIA, 2013).

Moreover, in the event of an accidental release to the atmosphere, LNG will evaporate at normal temperatures and disperse quickly without environmental disaster and therefore requiring no environmental cleanup (ERM, 2005, p2).

Economic: With regard to costs, DMA (2012) report suggests that LNG price has been slightly less volatile compared to other fuel sources for a selected period as illustrated in Figure 2.2. In addition, the outlook for future price development of oil versus natural gas indicates a significant price difference with gas being cheaper on average per energy content basis in the long term (McGill et al, 2013, p41).

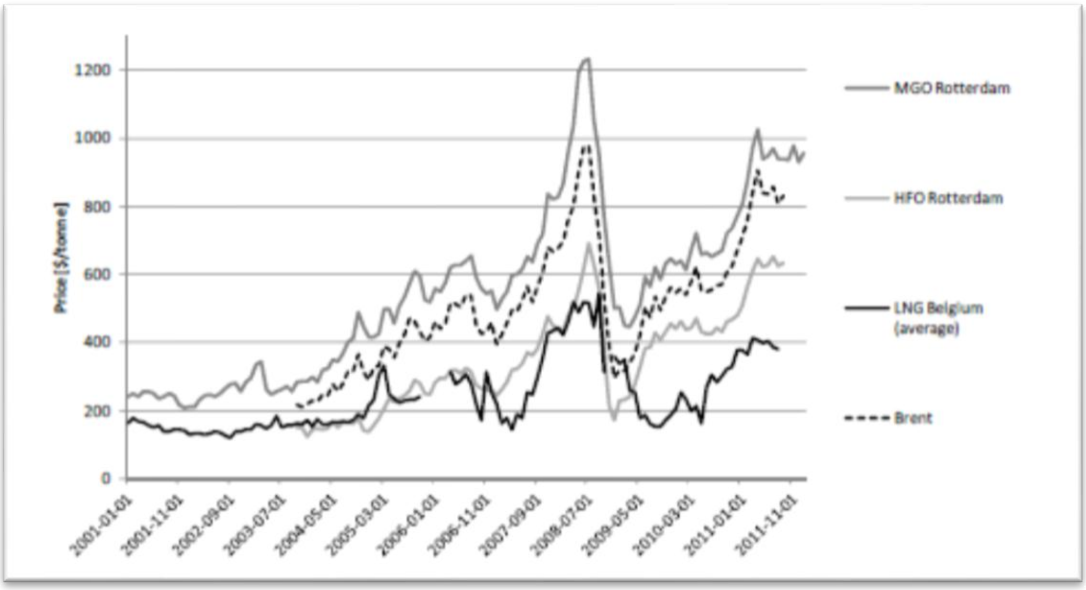


Figure 2.2: Historical prices in $/tonne (Source: DMA, 2012)

2.2.2 Disadvantages

Despite the advantages and benefits presented above, LNG poses a number of challenges and disadvantages which should also be considered and they are highlighted below.

Depletion: Natural gas is a non-renewable resource and this adds a dimension of scarcity and implies that although it is currently available in abundance to the foreseeable future, natural gas may eventually be depleted (Bhattacharyya, 2011, p356).

Greenhouse gas: Natural gas comprises mainly methane (CH4), which is an aggressive greenhouse gas and therefore poses a risk of global warming and air pollution when released into the atmosphere during operations (SSP, 2012,p50).

Economic and technical: the development of LNG supply chain infrastructure required to ensure the seamless flow of products is constrained by the inherent demand of security. This is because LNG is capital intensive and consequently makes the volume risk a major issue for producers as the customer has various alternatives available and ultimately complicates the global gas market (Bhattacharyya, 2011, p356; WEC, 2013, p15). This is also exacerbated by gas fields increasingly being further offshore and in remote areas (WEC, 2013, p15).

2.3 LNG Market Overview

LNG has been in existence for several years and recently witnessed rapid growth compared to other traditional fuel sources like oil. This growth has been largely attributed to the emergence of new importers from Asia, such as China and Japan to mention a few and many experts foresee the gas market to continue to grow in the upcoming years. In addition, increasing environmental pressure, oil prices and legislation throughout the world together with cost effective technology is causing consumers to opt for alternative forms of energy.

There is an abundance of natural gas in the world; however, the challenge of connecting natural gas supply to demand seems to persist from years back. Even though advanced technology has considerably reduced gas transportation costs through LNG, capital costs for LNG investment are significantly high and thus hamper the developments required to increase gas production and consumption (Cornelius, 2006). This section aims to provide a general overview of the LNG market and highlight the capacity of existing natural gas reserves, consumption and production together with trade and price dynamics. The discussion focuses on natural gas dynamics with inference to the potential LNG market.

2.3.1 Global Market

The following market overview is largely based on International Energy Outlook of the 2013 report compiled by US Energy Information Administration and the World Energy Resources Survey of 2013 as compiled by World Energy Council. The different world regions are grouped into Organisation for Economic Cooperation and Development (OECD) and non OECD and also distinguishing between developing and developed countries. OECD members are divided into three basic country groupings: OECD Americas (United States, Canada, and Mexico/Chile), OECD Europe, and OECD Asia (Japan, South Korea, and Australia/New Zealand). Non-OECD countries are divided into five separate regional subgroups: non-OECD Europe and Eurasia (which includes Russia); non-OECD Asia (which includes China and India); the Middle East; Africa; and Central and South America (which includes Brazil).

2.3.1.1 Reserves

According to USEIA (2013, p56), global reserves of natural gas have grown by 39% over the past two decades particularly in non-OECD countries since 1993. However, between 2012 and 2013 global reserves saw a small growth of less than 1% largely due to changes to proven natural gas reserves in Iran. Iran was the second-largest contributor and its proved natural gas reserves grew only by 2% over the period, thereby affecting the entire Middle East, which also grew modestly by 0.3% from 2012 to 2013.

In addition, China emerged and recorded a growth of 16% from the same period and became part of the top 20 world's proven reserves while Russia remains the largest as indicated in Table 2.1. Figure 2.3 also shows growth patterns of world proven natural gas reserves by region with non OECD leading the growth 1980 - 2013 (USEIA, 2013, p56).

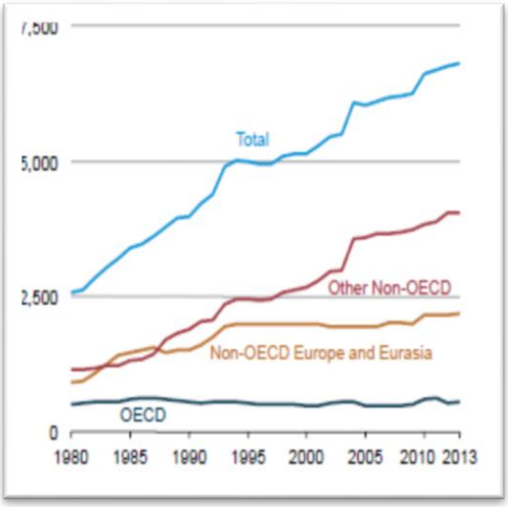


Figure 2.3: World proved natural gas reserves by region, 1980-2013(trillion cubic feet) (Source: USEIA, 2013)

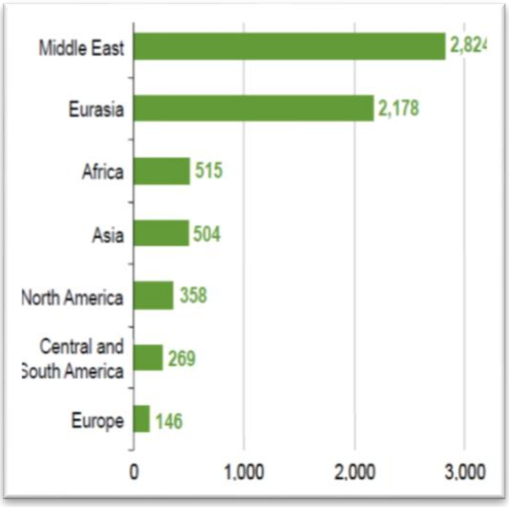


Figure 2.4 World proven natural reserves by geographic region as of January 1, 2013 (trillion cubic feet) (Source: USEIA, 2013)

It can also be observed from Figures 2.4 and 2.5 that proven natural gas reserves are distributed unevenly around the world and some are concentrated in Eurasia and the Middle East with Russia, Iran and Qatar accounting for about 55% and have fairly adequate resources for production.

On the other hand, OECD countries, including many in which there are relatively high levels of consumption, do not have sufficient resources for production (USEIA, 2013, p56). This has been largely attributed to the significant upfront investment required for exploration, development and transport of gas. Therefore, close coordination between investment in the gas and power infrastructure is necessary to bring gas to the market from these areas (WEC, 2013).

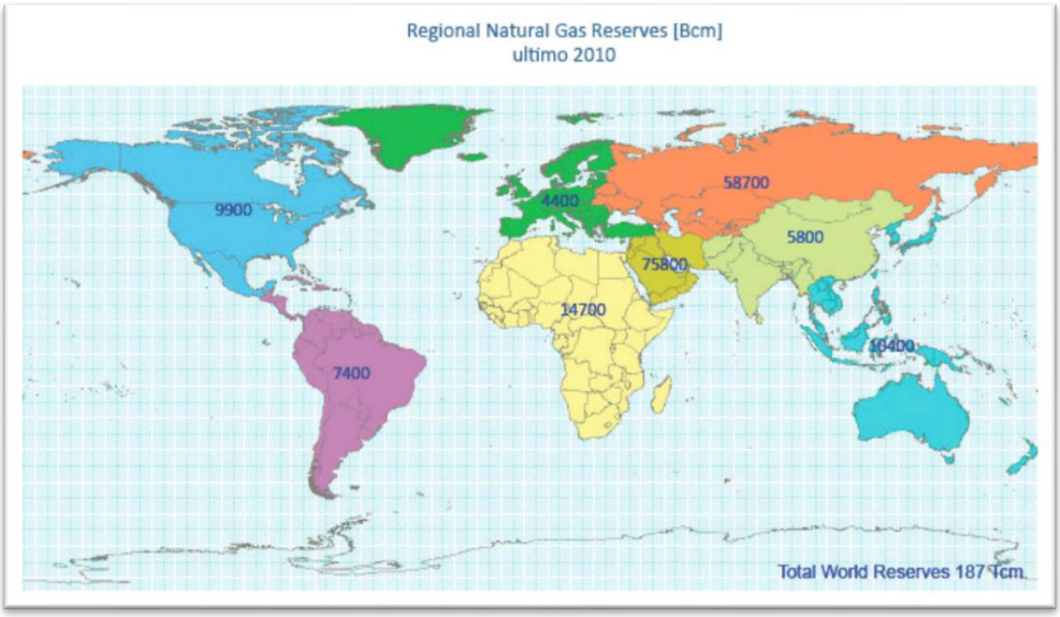


Figure 2.5: Proven gas reserves in the eight regions (Source: WEC, 2013, p130)

Table 2.1: National gas reserves – top 5 countries (Source: WEC, 2013)

Country	**Reserves (bcm)**		**Production**		**R/P**
	2011	1993	2011	1993	years
Russia	47 750	48 160	670	604	71
Iran	33 790	20 659	150	27	> 100
Qatar	25 200	7 079	117	14	> 100
Turkmenistan	25 213	2 860	75	57	> 100
Saudi Arabia	8 028	5 260	99	36	81
Rest of World	69 761	57 317	2 407	1 438	22
Global Totals	**209 742**	**57 317**	**2 407**	**1 438**	**55**

2.3.1.2 Production

Figure 2.6 provides an overview of natural gas production by country grouping as reported by USEIA (2013, p49). Non-OECD natural gas production grows by an average of 2%per year, from 70 trillion cubic feet in 2010 to 126 trillion cubic feet in 2040. The largest production increases are from 2010 to 2040 projected at 18.9 trillion cubic feet from Non-OECD and Eurasia show with Russia remaining dominant (USEIA, 2013, p49; WEC, 2013, p124). OECD Americas and the Middle East both projected at 15.9 trillion cubic feet and 15.6 trillion cubic feet respectively (Figure 2.4). OECD production grows by only 1.3% per year, from 41 trillion cubic feet to 61 trillion cubic feet (USEIA, 2013, p49) with OECD America showing a growth of 56% from 2010 to 2040.

The Middle East accounts for more than 40% of the world's proven natural gas reserves and consequently contributes about 21% of the total global production increase from 15.9 trillion cubic feet in 2010 to 31.5 trillion cubic feet in 2040. Other non OECD including Central and South American natural gas production is showing approximately 50% increase from 5.4 trillion cubic feet to 10.4 trillion cubic feet for the period 2010 to 2040 with Brazil and Argentina leading the region (USEIA, 2013, p55). In Asia, an increase of 9.7 trillion cubic feet from 2010 to 2040 has been projected, with China and India contributing 70% and 12% respectively. The largest OECD European producers are Norway, the Netherlands and the United Kingdom contributing 85% of total regional supply in 2010 with minimum growth projected.

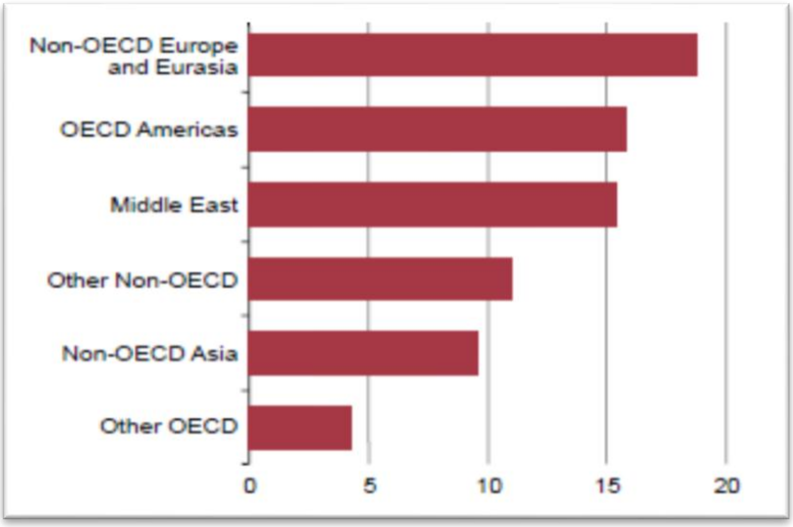


Figure 2.6: Global increase in natural gas production by country grouping, 2010 – 2040 (trillion cubic feet) (Source: USEIA, 2013)

2.3.1.3 Consumption

World natural gas consumption has been projected to increases by 64% from 113 trillion cubic feet in 2010 to 185 trillion cubic feet in 2040. Global consumption was affected by recession in 2009 with a decline of approximately 3.6 trillion cubic feet followed by significant recovery of about 7.7 trillion cubic feet in 2010, or 4% higher than demand in 2008, before the downturn. This indicates that natural gas remains a preferred source of energy throughout many regions in the world largely for power generation (USEIA, 2013, p3).

OECD Americas annual natural gas consumption is projected to increase steadily to 41.6 trillion cubic feet in 2040 and remains the largest consumer. OECD Europe natural gas consumption is expected to grow by 0.7% per year on average from 19.8 trillion cubic feet in 2010 to 24.5 trillion cubic feet in 2040 (USEIA, 2013, p46).

Figure 2.7 shows global natural gas consumption per capita for 2012 period. USEIA (2013, p46) has projected natural gas consumption in OECD Asia to grow on average by 1.3% per year from 2010 to 2040, from 6.7 trillion cubic feet to 9.9 trillion cubic feet. Japan accounted for the most natural gas consumption between 2010 to 2020 following the nuclear power lost during the Fukushima incident in March 2011. However, it is assumed that nuclear generation capacity may be reinstated, thereby resulting in minimum or new consumption growth in addition to declining population and aging workforce (USEIA, 2013, p46).

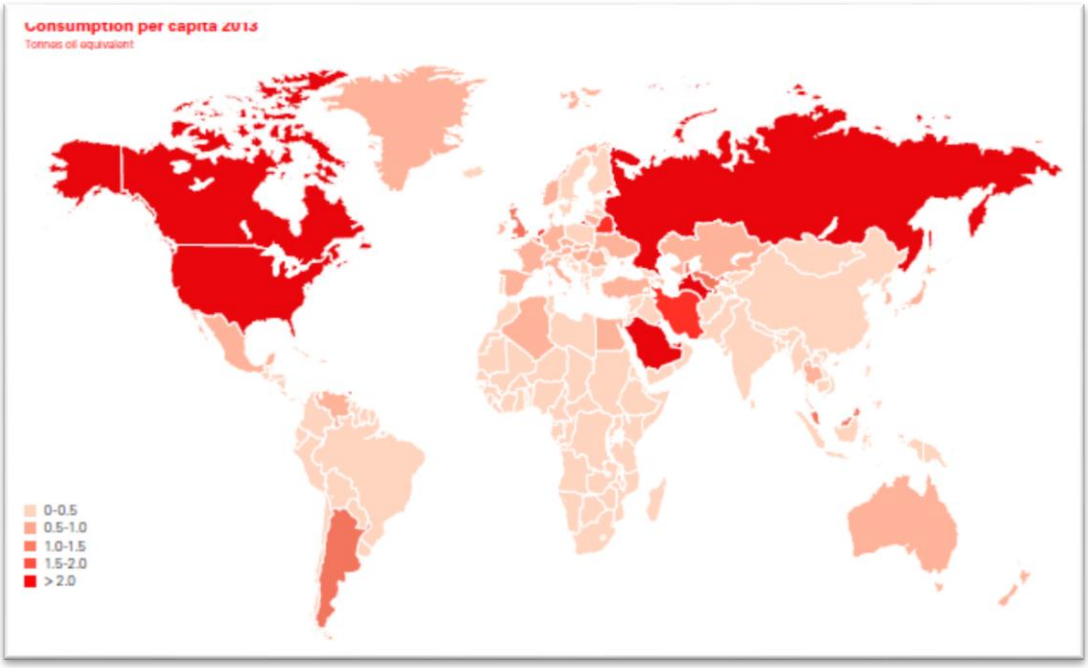


Figure 2.7: Natural gas consumption per capita (Source: BP, 2014)

On the other hand, the outlook for non OECD Europe and Euroasia showed natural gas reliance of 47.3% to meet domestic supply in 2010. The region also showed the highest consumption rate outside OECD America (Figure 2.7) with Russia accounting for 69% in 2010. Furthermore, non OECD Asia consumption is also growing fast from 13.9 trillion cubic feet in 2010 nearly tripling the amount to 36.3 trillion cubic feet in 2040 due to the demand from China. India and other OECD Asia are showing minimum growth for the same period (USEIA, 2013, p47-48). In the Middle East region, natural gas accounted for about one-half of total energy consumption in 2010 within the region, with a projected 2.2% increase to 2040 (USEIA, 2013, p48). Central and South America non-OECD region project an average increase of 2% per year in natural gas consumption from 4.9 trillion cubic feet in 2010 to 8.9 trillion cubic feet in 2040.

2.3.1.4 Trade

World natural gas is transported to the markets through pipelines and as LNG using specially designed ships and major trade movements are reflected in Figure 2.8. Considering the advantage of transportation over long distances where pipelines are not viable, LNG contributes to a growing share of world natural gas trade which is expected to double from approximately 10 to 20 trillion cubic feet between 2010 to 2040 (WEC, 2013, p3-13; BP, 2013, p53).

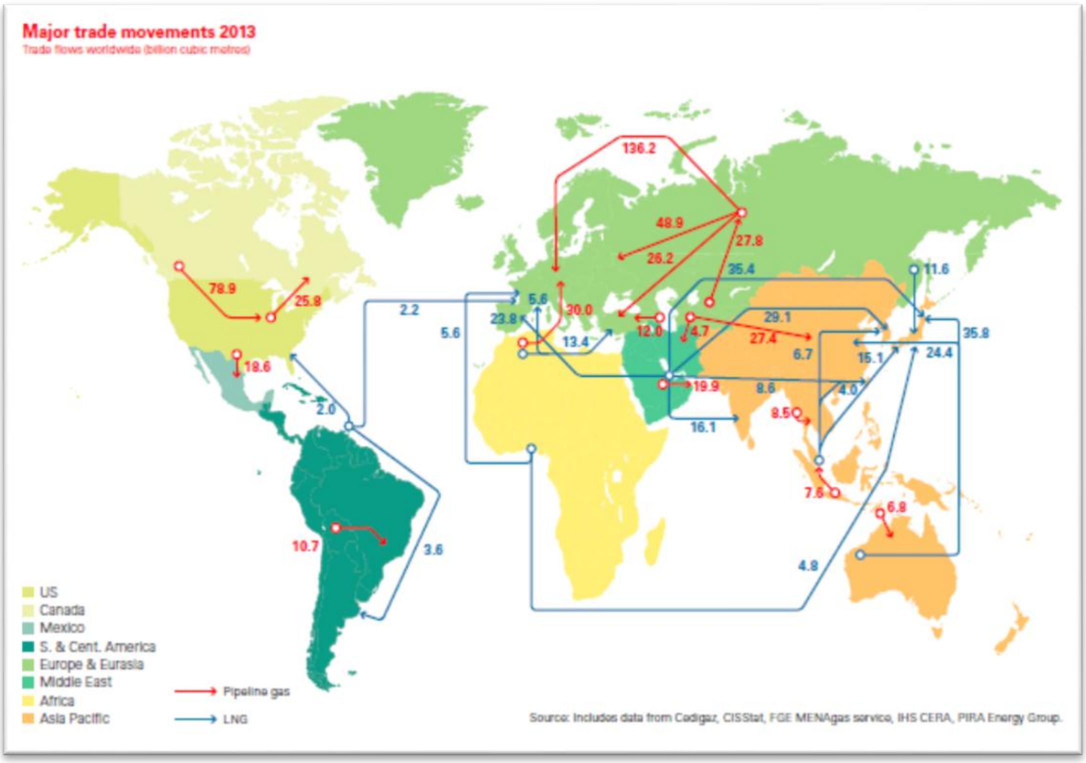
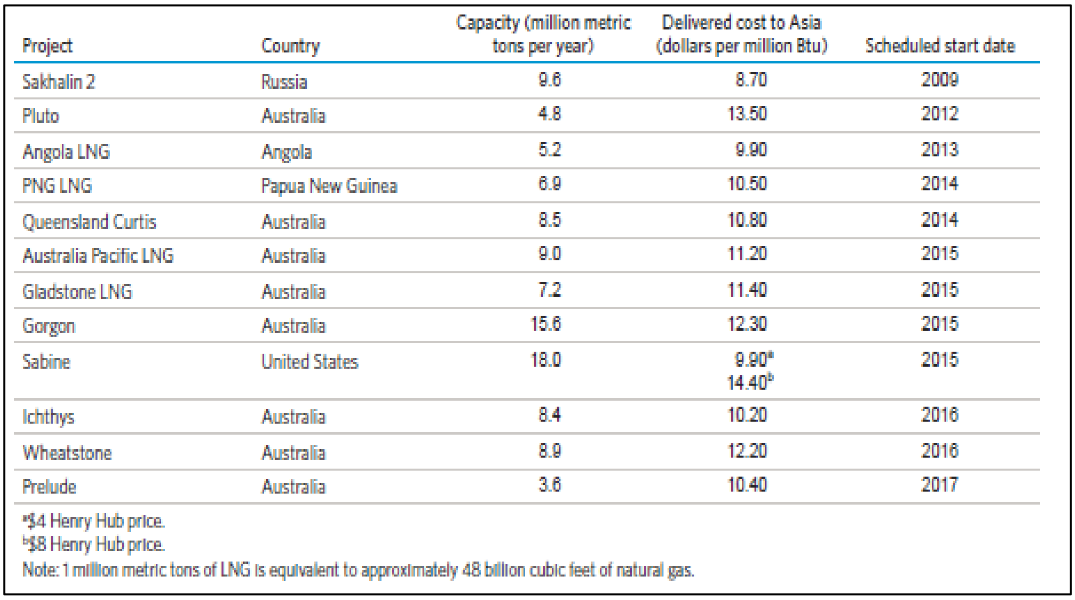


Figure 2.8: Major trade movements 2013 (Source: BP, 2014)

However, LNG requires liquefaction capacity which has already been projected to increase in the short and long term as indicated in Table 2.2. Australia and North America are expected to increase production in a short term. WEC (2013, p3-13) adds that there is additional capacity expected from Qatar, Papua New Guinea and Indonesia. On the other hand, existing facilities in North Africa and Southeast Asia have been underutilized or are shutting down as a result of production decline at older fields associated with the liquefaction facilities, and because domestic natural gas consumption is more highly valued than exports (WEC, 2013, p3-13).

Table 2.2: Selected LNG liquefaction projects existing and under construction (Source: USEIA, 2013)



Project	Country	Capacity (million metric tons per year)	Delivered cost to Asia (dollars per million Btu)	Scheduled start date
Sakhalin 2	Russia	9.6	8.70	2009
Pluto	Australia	4.8	13.50	2012
Angola LNG	Angola	5.2	9.90	2013
PNG LNG	Papua New Guinea	6.9	10.50	2014
Queensland Curtis	Australia	8.5	10.80	2014
Australia Pacific LNG	Australia	9.0	11.20	2015
Gladstone LNG	Australia	7.2	11.40	2015
Gorgon	Australia	15.6	12.30	2015
Sabine	United States	18.0	9.90[a] 14.40[b]	2015
Ichthys	Australia	8.4	10.20	2016
Wheatstone	Australia	8.9	12.20	2016
Prelude	Australia	3.6	10.40	2017

[a] $4 Henry Hub price.

[b] $8 Henry Hub price.

Note: 1 million metric tons of LNG is equivalent to approximately 48 billion cubic feet of natural gas.

An overview of natural gas production indicates that there is interest in developing unconventional gases (tight gas, shale gas, and coalbed methane) as they are showing a significant growth. However, the development of unconventional gas will not necessarily negate the growing international trade as the anticipated LNG liquefaction projects have already considered existing tight and shale gas reserves. Nevertheless, WEC (2013) outlook shows that Asia Pacific will continue to be the largest LNG importer accounting half of total LNG imports by 2030. Europe and Continental Asia follow but the two regions' combined LNG imports are still below that of Asia Pacific. Three other regions also import LNG, but in smaller quantities - North America, Latin America and the Middle East (WEC, 2013, p3.13).

2.3.1.5 Pricing

There is currently no common international pricing mechanism for natural gas and as a result, regional gas prices vary around the world as indicated in Figure 2.9. However, some of the mechanisms currently used include oil linked pricing, regulated pricing, and competitive market pricing. Oil linked pricing links natural gas trade to long term oil prices with a certain discount and regulated prices are established by governments. Competitive pricing on the other hand, sets out trading points to be used by suppliers and consumers to determine the price (USEIA, 2013, p45).

Figure 2.9: Average price per region (Source: WEC, 2013, p3.7)

The use of diverse price mechanisms around the world creates complexities and leads to enhanced international trade to exploit arbitrage opportunities. This is putting pressure on customers and suppliers to align their prices to traded markets. Although there is uncertainty regarding the future price mechanism that will persist, both USEIA and WEC anticipate that the competitive natural gas market will eventually dominate. Lowell et al., (2013, p5) also note that natural gas fuel prices have decoupled from those of petroleum fuels. Other regions such as North America and Europe are making progress towards a competitive approach (Figure 2.10) and it is expected that Asia may also adopt the same approach in the future (USEIA, 2013, p45).

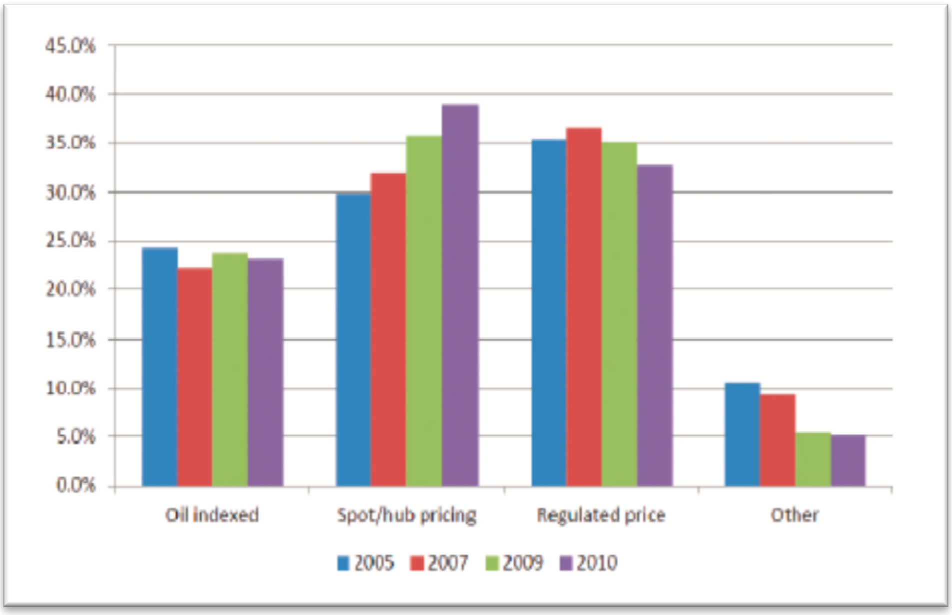


Figure 2.10: Gas is increasingly priced on the basis of gas hubs (Source: WEC, 2013)

2.3.2 African Market

2.3.2.1 Reserves

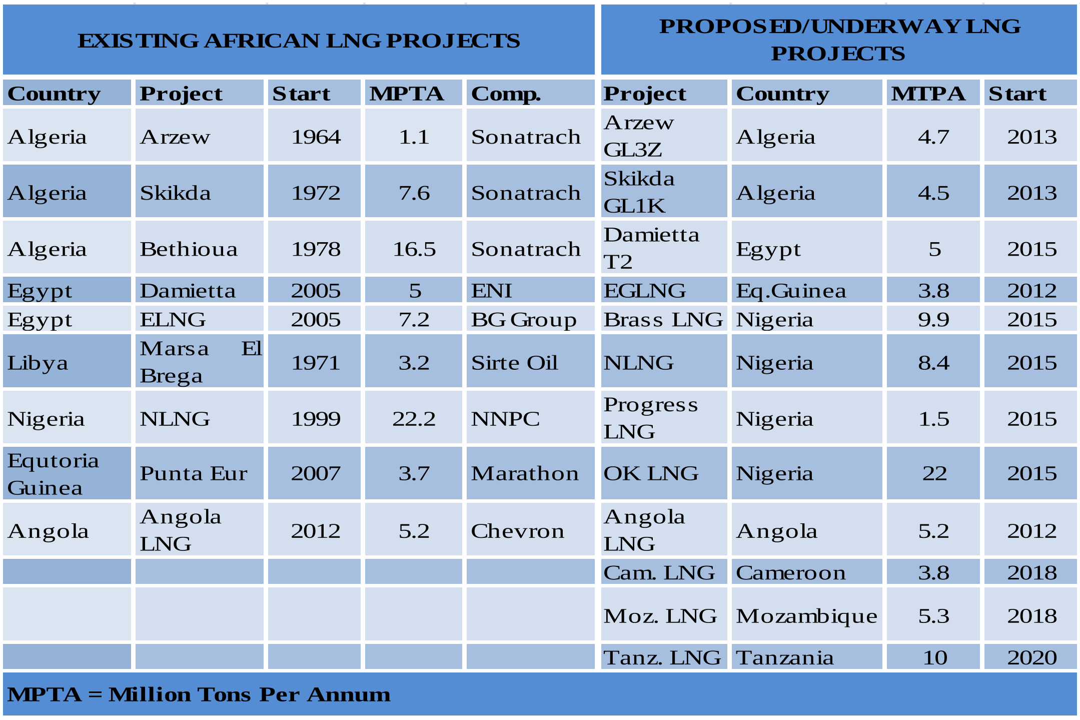
According to BP (2014), proved reserves of natural gas in Africa are estimated at around 501 trillion cubic feet by end of 2013 accounting for 7.6% of the world’s total. Algeria and Nigeria holds the biggest share at 159 trillion cubic feet and 179.4 trillion cubic feet respectively (BP, 2014). In East Africa, several new natural gas fields have been discovered recently near the common border of Mozambique and Tanzania. Oil and gas companies are estimating 85 trillion cubic feet and 18 trillion cubic feet of recoverable gas for both Mozambique and Tanzania respectively (Denton-Brown & Thormet, 2014, p7).

2.3.2.2 Production

Gas production in Africa is expected to grow from 7.4 trillion cubic feet in 2010 to 13.6 trillion cubic feet in 2040. On a regional level, Africa is set to overtake the Middle East to become the largest net LNG exported in 2028 (BP, 2013, p53; Brown & Thormet, 2014, p7). North Africa (Algeria, Egypt and Libya) has been the main contributor at 79% in 2010, while West Africa accounted for another 19% and the rest of Africa accounted for just 2%. However, West Africa is showing a lot more potential with Nigeria increasing production (Denton-Brown & Thormet, 2014, p7).

In addition, Equatorial Guinea and Angola have increased regional production with the inclusion of new LNG facilities (USEIA, 2013, p53). East African LNG liquefaction projects have already advanced with the major target market in Asia (USEIA, 2013, p53; Denton-Brown & Thormet, 2014, p7). Table 2.3 provides a view of recently built and proposed LNG plants around Africa.

Table 2.3: Existing and Proposed LNG Capacity in Africa (Source: alifarabia.com)



EXISTING AFRICAN LNG PROJECTS					**PROPOSED/UNDERWAY LNG PROJECTS**			
Country	**Project**	**Start**	**MPTA**	**Comp.**	**Project**	**Country**	**MTPA**	**Start**
Algeria	Arzew	1964	1.1	Sonatrach	Arzew GL3Z	Algeria	4.7	2013
Algeria	Skikda	1972	7.6	Sonatrach	Skikda GL1K	Algeria	4.5	2013
Algeria	Bethioua	1978	16.5	Sonatrach	Damietta T2	Egypt	5	2015
Egypt	Damietta	2005	5	ENI	EGLNG	Eq.Guinea	3.8	2012
Egypt	ELNG	2005	7.2	BG Group	Brass LNG	Nigeria	9.9	2015
Libya	Marsa El Brega	1971	3.2	Sirte Oil	NLNG	Nigeria	8.4	2015
Nigeria	NLNG	1999	22.2	NNPC	Progress LNG	Nigeria	1.5	2015
Equtoria Guinea	Punta Eur	2007	3.7	Marathon	OK LNG	Nigeria	22	2015
Angola	Angola LNG	2012	5.2	Chevron	Angola LNG	Angola	5.2	2012
					Cam. LNG	Cameroon	3.8	2018
					Moz. LNG	Mozambique	5.3	2018
					Tanz. LNG	Tanzania	10	2020
MPTA = Million Tons Per Annum								

2.3.2.3 Consumption

Africa’s natural gas consumption is projected to increase to 8.8 trillion cubic feet from 2010 to 2040. The average annual growth rate of natural gas use, at 3.1%t, is second only to that of nuclear energy, which increases by 6.8% per year from 2010 to 2040. Egypt and Algeria are Africa’s two largest consumers and producers of natural gas, together accounting for more than 74% of the region’s total natural gas consumption and 70% of its production in 2010. Most of Nigeria’s marketed production is exported as LNG, the remainder is consumed domestically (USEIA, 2013, p48).

2.3.2.4 Trade

Natural gas trade is expected to grow at an annual rate of 0.9% in Africa. A total of about 3.8 trillion cubic feet was exported from the region in 2010 with North Africa accounting for 2.8 trillion cubic feet. Between one-half and two-thirds of the exports from North Africa are delivered by pipeline from Algeria, Egypt, and Libya to Spain, Italy, and parts of the Middle East. The balance was exported as LNG to different markets, mainly to European countries. However, natural gas exports have declined from Egypt since 2011 due political events, pipeline sabotage and government decision to prioritise domestic consumption over exports (USEIA, 2013, p60).

On the other hand, West Africa and East Africa are showing a strong average growth rate of 4.5% from 2010 to 2040. In West Africa, specifically Nigeria, proposed LNG projects have been significantly delayed due to security concerns and over terms of access. East Africa is also facing major challenges as recent production and export proposals require an overhaul of existing operations for oil and gas in Mozambique and Tanzania. As a result, physical and regulatory infrastructures are not yet in place to support large-scale production and export of natural gas (USEIA, 2013, p60).

2.3.3 South African Market

2.3.3.1 Reserves

According to USEIA (2014,p7), South Africa (SA) has very large shale gas resources of about 390 trillion cubic feet that are technically recoverable, making the country the eighth-largest holder of technically recoverable shale gas resources in the world. Technically recoverable resources represent the volumes of oil and natural gas that could be produced with current technology, regardless of oil and natural gas prices and production costs. However, shale gas is currently a sensitive matter under debate from a political and an environmental standpoint (DOE, 2013; USEIA, 2014, p8). In addition, SA has material coal bed methane reserves of natural gas which can be appraised and then extracted and exploration is still in the early development stages (Ernest Young [EY], 2013).

Furthermore, SA has limited proven gas reserves and produces small volume of natural gas from declining offshore fields which are mainly used to supply Mossel Bay Gas to Liquid (GTL) plant via a pipeline. As a result, SA imports natural gas from Mozambique via pipeline to supply Sasol Secunda Coal to Liquid (CTL) plant and to fuel some gas fired power plants. Mozambique has also recently discovered new natural gas reserves, which may also be offered to SA. However, given the distance of new reserves to the existing pipeline to SA, LNG imports may become attractive transportation option (USEIA, 2014).

2.3.3.2 Production

Figure 2.11, illustrate that SA produced 39 billion cubic feet of natural gas and consumed 166 billion cubic feet; the difference was imported from Mozambique via pipeline in 2012 (USEIA, 2014, p7). In addition, PetroSA has offshore production of about 20 billion cubic metres from gas fields located south of Mossel Bay and this is dedicated to run its gas to a liquid refinery. The current gas fields are depleted and PetroSA is exploring undeveloped areas for more natural gas (DOE, 2013, p39).

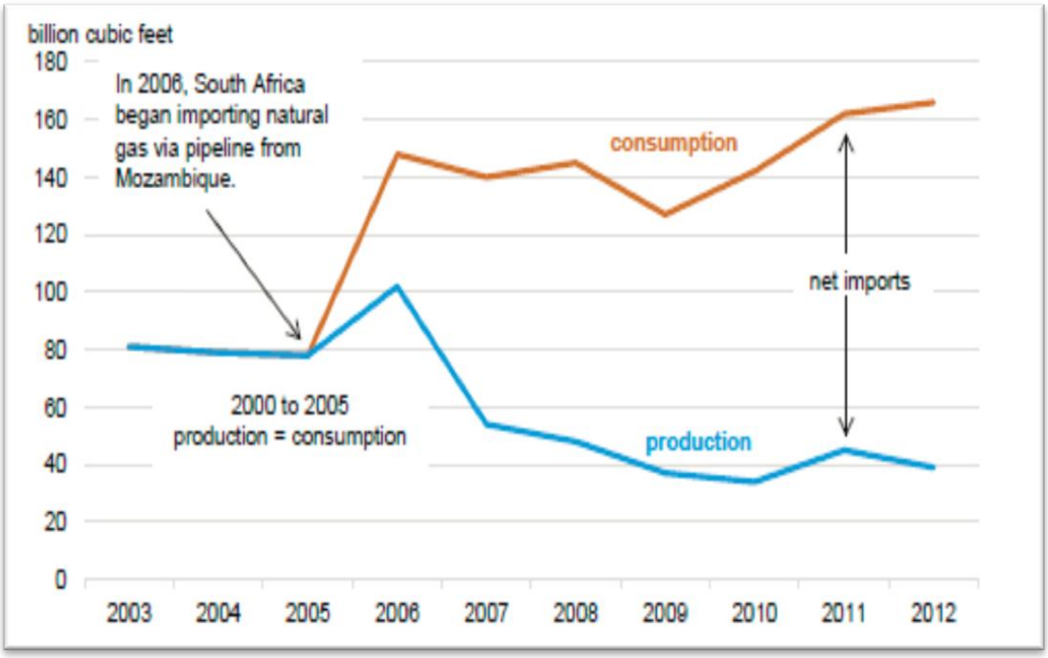


Figure 2.11: South Africa's natural gas production and consumption, 2003-2012 (Source: USEIA, 2014)

2.3.3.3 Consumption

As it can be noted from Figure 2.11, SA consumed 166 billion cubic feet natural gas in 2012 (USEIA, 2014, p7). The Department of energy also reported that natural gas consumption currently exceeds production as illustrated in Figure 2.11 (DOE, 2013, p39). Current consumption for natural gas in SA is mainly for the GTL and chemicals industries, where PetroSA, Sasol and some industry users are the major players. Sasol Gas imports natural gas from Mozambique and utilises most of this in its own chemical and GTL facilities (Hietkamp, 2013). Sasol has exclusive rights to the transmission and distribution network for gas imported from Mozambique and has more than 500 industrial customers and gas traders, but also satisfies the demand from local gas distributors (Price Waterhouse Coopers [PWC], 2012, p17).

The domestic gas market is therefore mainly made up of GTL plants and industrial users, and the lack of an extensive transmission and distribution network is seen to be a significant barrier to increasing the demand from commercial and residential customers. On the industrial side, Integrates Resource Plan, rev.2 (IRP2) makes provision for gas-fired power generation, and it is expected that this will stimulate demand and consumption for gas in South Africa (PWC, 2012, p17). In the absence of own proven natural gas reserves, the proposed gas fired power facility presents an opportunity of being an anchor customer for large volumes required to make LNG infrastructure feasible. It is expected that LNG imports will provide security of supply and unlock development of distribution network to increase demand from commercial and residential customers (PWC, 2012, p18).

2.4 LNG as Marine Fuel

According to Blikom (2012) LNG has been proven to be a technically viable marine fuel for commercial ships. The option to use LNG as marine fuel was triggered by environmental pressure to reduce greenhouse emissions, legislation and the increasing fuel prices. The following discussion provides an overview of these driving factors in order to understand the basis for LNG as marine fuel. Alternative marine fuel options will also be compared to LNG to assess benefits and challenges for each.

2.4.1 Drivers for LNG

2.4.1.1 Overview of regulations

The International Maritime Organisation (IMO) is the most relevant organisation responsible for safety, security and environmental issues related to shipping. This responsibility is discharged through the development of international regulations and other instruments to address maritime issues. IMO has since developed International Convention on the Prevention of Pollution from Ships (MARPOL 73/78) to specifically prevent pollution from ships. In particular, air pollution issues are regulated through Annex VI titled “Regulations for the prevention of Air Pollution from ships”.

Annex VI limits the main air pollutants contained in ships exhaust gas, including nitrous oxides (NOx) and sulphur oxides (SOx) and prohibits deliberate emissions of ozone depleting substances. The requirements are defined in two categories for global requirements and more stringent requirements applicable to ships in Emission Control Areas (ECA). The requirements are being implemented progressively and will be in full force as illustrated in regulations roadmap in Figure 2.12 (DNV, 2013, p16; American Bureau of Shipping [ABS], 2014, p2).

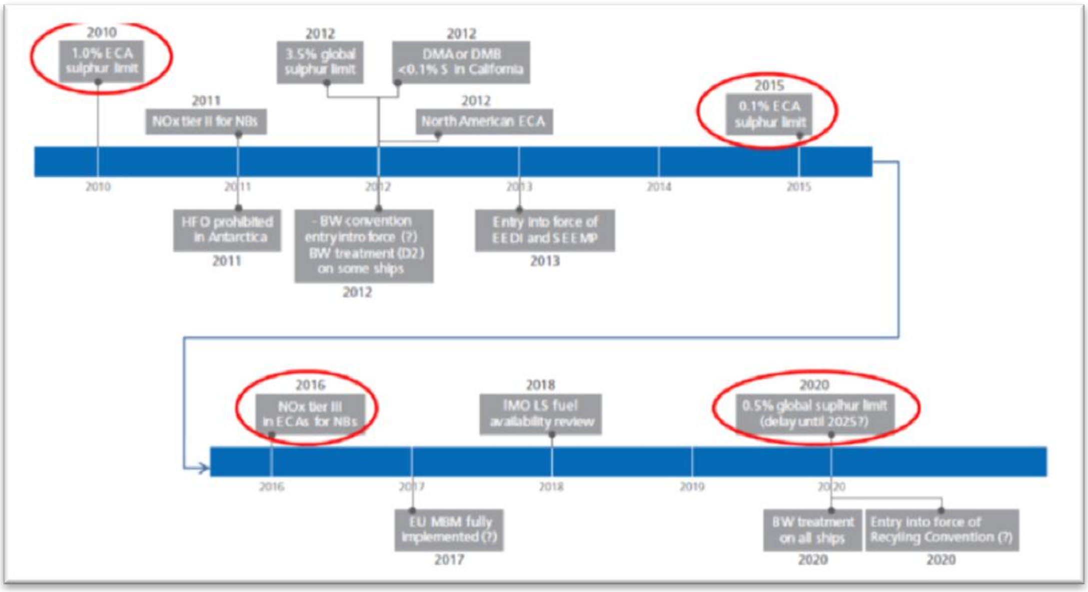


Figure 2.12: Regulations roadmap (Source: DNV, 2013)

Annex VI also makes provision for coastal states to designate part of the sea as Emission Control Area (ECA) in order to prevent or reduce adverse impacts on human health and the environment. An ECA can cover NOx, SO2 or PM or all three types of emissions. A Sulphur Emissions Control Area is called a SECA and a Nitrogen Oxide Emissions Control Area is subsequently called a NECA (Ballini, 2013, p12). Current ECAs only include the Baltic Sea, the North Sea and North America as illustrated in Figure 2.13 and they will be expanding further to other countries in the near future 2014 (DNV, 2014, p16).

Figure 2.13: Existing and potential new ECAs (Source: SSP, 2012)

a) SOx limitations

Emissions of SOx are addressed in regulation 14 of Annex VI, which caps sulphur emissions from marine fuel globally <4.5% for non-ECA regions and <0.1% in ECA regions from 2015. The revised Annex VI came into force on 01 July 2010 and further reduced SOx global content in marine fuels from 4.5% to 3.5% maximum. SOx emissions in non-ECA regions are also set to be limited to 0.5% between 2020 and 2025 pending a feasibility assessment to be performed in 2018 (Figure 2.14). Implementation of target of 0.5% limit between 2020 and 2025 is expected to increase the adoption of LNG as marine fuel worldwide (Semolinos et al., 2011, p3; DNV, 2013, p7).

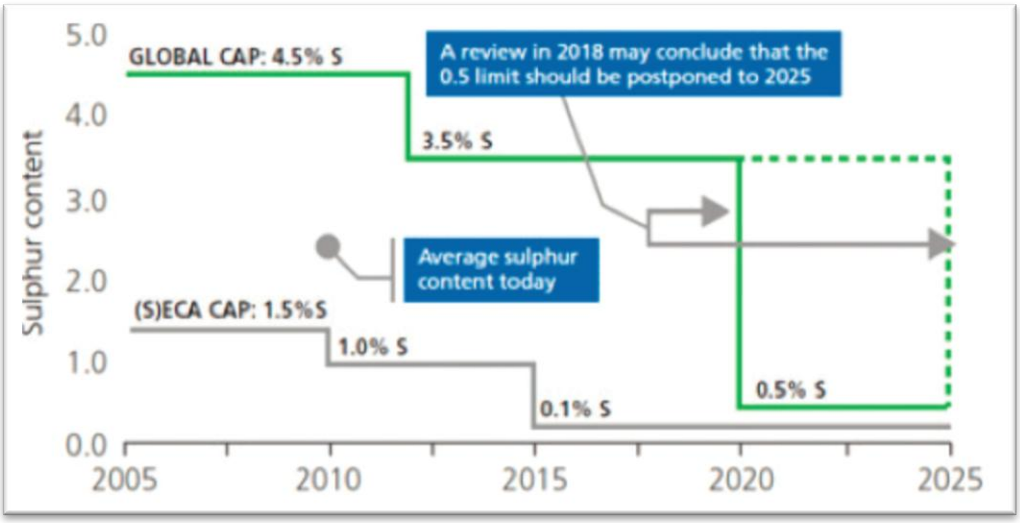


Figure 2.14: Timeline for Sulphur Limits

(Source: Adamchak & Adebe, 2013)

b) NOx limitations

Regulation 13 of Annex VI deals with NOx and defines emission limits based on year of vessel construction and engine speed within a three-tier system indicated in Table 2.4. Ships built between 2000 and 2011 need to comply with NOx emissions at maximum engine speed of about 9.8–17 gramme per kilowatt-hour (g/kWh) (Tier I), those built after 2011 need to comply with 7.7–14.4 g/kWh (Tier II), and ships operating after 2016 in so-called NOx Emission Control Areas (NECAs) need to comply with emissions of 2.0– 3.4 g/kWh (Tier III) (EEA, 2013, p12).

Table 2.4: NOx limits for new builds (Source: IMO, 2009)

Tier	**Applicable areas**	**Construction year**	**NOx Limit, g/kWh (n = rpm, below)**		
			$n < 130$	**$130 \le n < 2000$**	**$n \ge 2000$**
Tier I	Global	2000	17.0	$45 * n^{-0.2}$	9.8
Tier II	Global	2011	14.4	$44 * n^{-0.23}$	7.7
Tier III	ECA	2016	3.4	$9 * n^{-0.2}$	1.96

c) Particulate Matter limitations

Annex VI provisions for SOx limitations indirectly reduce Particulate Matter (PM) emissions. However, special limits for PM are expected to be implemented in the future (DNV, 2013, p18).

2.4.1.2 Environmental Impacts of Shipping Emissions

Shipping contributes significantly to air pollution by the emissions of CO_2, NOx and SOx from the transport sector. This is as a result of the current dominant fuel type heavy fuel oil which has high SOx and NOx in comparison to other energy sources such as gasoline and gasoil. Eyring et al., (2009, p1) indicate that the highest exposure levels of air pollution by shipping are found in ports and near coastlines, because 80% of the world fleet is positioned in ports or navigating in coastal areas. Big human populations are often found in port cities or coastal areas, hence high exposure to ship emissions. In addition, coastal areas provide habitat to several sensitive ecosystems and they are also exposed to ship air pollution (Eyring et al., 2009, p1; van der Meer, 2012, p13).

a) Human health

Sulphate and nitrite particles from SOx and NOx contribute to the concentrations of airborne particles (PM). Exposure to ambient concentrations of PM has been linked to various health impacts such as mortality (especially from cardio-vascular and cardio-pulmonary diseases) and morbidity. Corberett et al., (2007) as cited by Eyring et al., (2009, p20), has proved that PM emissions account for about 60000 premature mortalities annually from cardiopulmonary disease and lung cancer. Eyring, Corbett, Lee, & Winebrake, (2007, p3), added that this mortality estimate does not account for additional health impacts such as respiratory illnesses like bronchitis, asthma, and pneumonia. With reference to the WHO report, European Environmental Bureau [EEB], (2004, p4) indicated that the effect of PM on life expectancy may be in the order of one to two years.

b) Ground-level ozone

As mentioned earlier, the highest exposure levels to shipping emissions occur within ports and near the coast with heavy traffic. These emissions contribute to the formation of ground-level ozone which poses a health hazard and damage to vegetation. Eyring et al., (2009, p1) adds that ozone and aerosol precursor emissions may be transported in the atmosphere further inland and affect air quality. In the Mediterranean region, it has been reported high concentrations of ozone is also posing a threat to the region's important tourism industry (EEB, 2004, p4).

c) Eutrophication

Nitrogen oxides from shipping cause eutrophication of natural ecosystems and freshwater bodies and pose a risk to biodiversity through excessive nitrogen input (Kageson, 2005, p3). According to European Environmental Bureau, shipping is the largest single source of acidification and eutrophication fallout over many countries in Europe despite an international nature of ship operations (EEB, 2004, p4).

Emissions from ship traffic contribute to exceedances of critical loads of acidity along coastal areas (EEB, 2004, p4) and cause acidification of terrestrial and freshwater ecosystems, damage materials (e.g. buildings and monuments), and have a negative impact on human health (Kageson, 2005, p10).

d) Corrosion

Ship emissions such as sulphur dioxide, nitrogen oxides, and ozone accelerate the rate of deterioration of a large number of various materials. Buildings and monuments made of limestone and some kinds of sandstone are especially sensitive to attack from acidic substances. Also metals become corroded more quickly in an acid environment. Ozone is known to speed up the disintegration of textile materials, leather and rubber (EEB, 2004, p5).

e) Climate change

Emissions from seagoing ships contribute to global climate change either directly, by acting as agents that trap heat in the atmosphere, or indirectly by aiding in the creation of additional greenhouse gases (Eyring et al., 2007, p4; Harould-Kolieb, 2008, p4). For example, the modification of the balance between incoming solar and outgoing terrestrial radiation is referred to as radioactive forcing. A briefing document prepared by European Environmental Bureau (EEB) and other agencies show that an estimate of radioactive forcing due to CO_2 emissions from ships indicates that ships may account for 1.8 per cent of the global warming (EEB, 2004, p5).

2.4.1.3 Economic

It has been widely agreed that future demand of LNG as marine fuel will largely depend on availability and price difference between LNG and other alternative fuel options (DNV, 2013,p8). The outlook for future price development of oil versus natural gas indicates a significant price difference with gas being cheaper on average per energy content basis in a long term (Blikom, 2012). Fuel price scenario compiled by GL (2011) also project LNG price below compared to other fuel types (Figure 2.15).

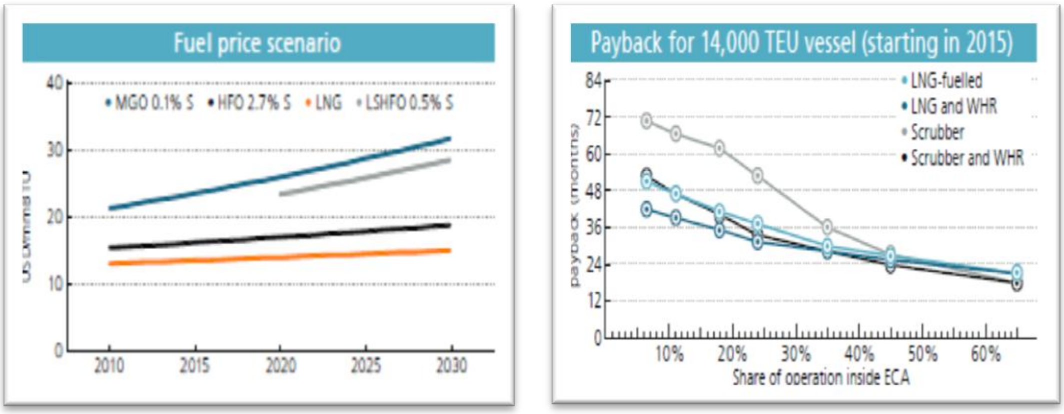


Figure 2.15: Fuel price scenario and LNG payback time (Source; GL, 2011)

Cheaper costs for gas have been attributed to the abundance of natural gas reserves available to be developed compared to declining oil reserves (Lowell et al., 2013, p4; Verbeek et al., 2011, p8). In addition, a DMA (2012) report suggests that the LNG price has been slightly less volatile compared to other fuel sources for selected period as illustrated earlier in Figure 2.2.

However, the use of LNG as marine fuel has been limited due to the relatively expensive infrastructure. For instance, the cost of an LNG engine plus LNG fuel tank system is about twice as high as a diesel engine plus fuel tank. Additional costs of Selective Catalytic Reduction (SCR) catalysts necessary for diesel engines in 2016 and later represent only 25% of the additional costs of the LNG fuel system plus storage. Although capital costs for installation of LNG infrastructure are high compared to other two options, the economic case for LNG is derived from cheaper LNG price to compensate for the investment in the long run (Verbeek et al., 2011, p5).

Moreover, a study conducted by GL (2011), also demonstrate that LNG system offers shorter payback time than a scrubber for large vessel (using the standard fuel price scenario). This is illustrated in Figure 2.15 and it should be noted that only at higher ECA operation share, the scrubber solution has a shorter payback time and this is unlikely.

2.4.2 Compliance Options

There are number of compliance strategies for ship owners to ensure compliance with IMO regulatory requirements, but the three main options include use of low sulphur fuel oil/marine gas oil (MGO), heavy fuel oil (HFO) with an exhaust gas scrubber and LNG. According to Lloys’s Register, all three options are considered to be feasible and the choice of compliance strategy depends on ship type and trade patterns (Aagesen, 2012, p2). On the other hand, DMA (2012, p59) indicates that the dominant option will depend on economic (investment costs) and operational factors and most importantly future fuel prices.

a) Heavy Fuel Oil with Exhaust Gas Scrubber

HFO is currently the dominating fuel type and would require the application of scrubbers for SOx (and PM) removal together with Selective Catalytic Reduction (SCR) or Exhaust Gas Recirculation (EGR) to remove NOx in order to comply with SECA requirements. As a dominant fuel type, HFO has existing infrastructure for bunkering. Scrubber technology is also readily available and ship owners do not need to retrofit or replace their engines. Scrubber tests show that the sulphur emissions are reduced to almost zero and the PM content in the exhaust gases is significantly reduced (DMA, 2012, p60; SSP, 2012, p50).

Disadvantages for HFO include required investments and off hire time for conversion. Scrubbers generate waste and there is currently no infrastructure available for disposal in ports. Nevertheless, eventual disposal of this waste will have cost implications. In addition, scrubber technology does not reduce CO_2 and may also occupy space and in some cases cargo capacity in other types of ships (Adamchak & Adebe, 2013, p3; SSP, 2012, p50). Selimolinos et al., (2011) adds that scrubbers may cause problems of stability for some ships, since the exhaust gas treatment has to be installed on top of the exhaust stack.

b) Marine Gas Oil (MGO)

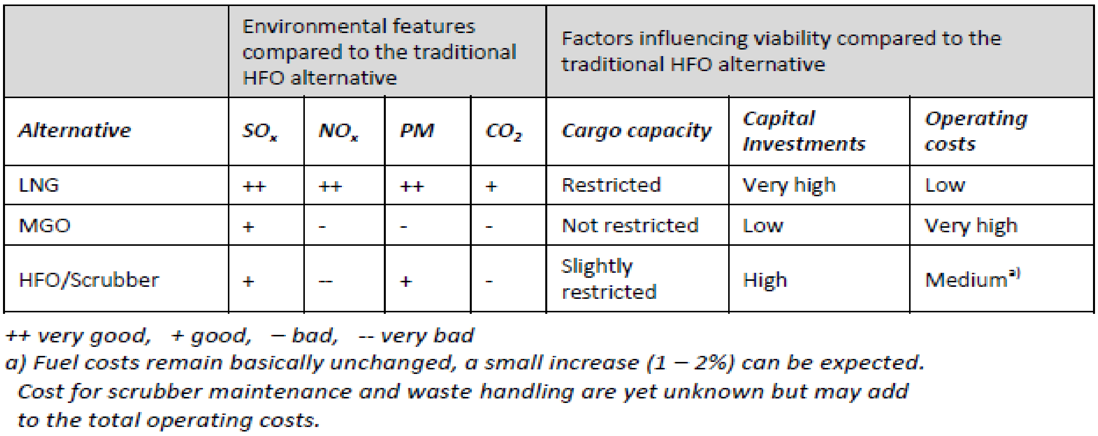
MGO offer an alternative to comply with SECA requirements as it has low sulphur emissions content and reduced particulate matter. However, compliance with NOx and greenhouse gas requirements will need the application of SCR or ECR to meet Tier III level. In comparison to LNG, MGO does not require additional space for storage tanks and retrofitting of the engine involves minimum or no investment costs. However, the current fuel price for MGO is already high and the outlook is indicating a further significant increase compared to other fuel types (DMA, 2012, p60; SSP, 2012, p50).

c) Liquefied Natural Gas (LNG)

LNG technology is known and well proven and many stakeholders continue to seek optimization of both costs and engine efficiency. One of the key advantages for LNG is that engines require less maintenance as gas combustion is significantly cleaner than its HFO or MDO counterparts (Semolinos et al., 2011, p6). As a clean fuel, it offers a good alternative to comply with Annex VI requirements by reducing SOx, NOx, PM and CO_2 emissions (DMA, 2012, p60; SSP, 2012, p50; DNV, 2013, p18).

However, there are also some drawbacks as the space occupied by LNG tanks is higher and may reduce cargo capacity for most types of vessels. The main disadvantage that has been widely identified is the availability of LNG as marine fuel constrained by the supply chain (SSP, 2012, p50; DNV, 2013, p18). This makes LNG unsuitable for ships which require flexibility in their routes. Retrofitting of required LNG equipment is costly and increased safety requirements result in construction of additional features contributing to higher costs (Semolinos et al., 2011, p6; McGill, 2013, p42). Table 2.5 provides a summary pros and cons for different compliance options.

Table 2.5: Comparing compliance options (Source: SSP, 2012)



	Environmental features compared to the traditional HFO alternative				Factors influencing viability compared to the traditional HFO alternative		
Alternative	*SO_x*	*NO_x*	*PM*	*CO_2*	*Cargo capacity*	*Capital Investments*	*Operating costs*
LNG	++	++	++	+	Restricted	Very high	Low
MGO	+	-	-	-	Not restricted	Low	Very high
HFO/Scrubber	+	--	+	-	Slightly restricted	High	Medium[a)]

++ very good, + good, – bad, -- very bad

a) Fuel costs remain basically unchanged, a small increase (1 – 2%) can be expected. Cost for scrubber maintenance and waste handling are yet unknown but may add to the total operating costs.

CHAPTER 3 – LNG BUNKERING INFRASTRUCTURE OPTIONS

Global abundance of natural gas is clearly evident from the previous chapter; however, the development of infrastructure remains a challenge. The following chapter provides an overview of natural gas and LNG infrastructure from a continental level in Africa to South Africa. Once the infrastructure has been established, natural gas and LNG demand will be analyzed from a land based perspective and as marine fuel for ships. LNG demand as marine fuel will be used as the basis for the development of a proposed bunkering supply chain in identified ports and will also look at bunkering solutions for consideration. Furthermore, infrastructure requirements for the proposed LNG bunkering supply chain will be identified for investment analysis in the following chapter.

3.1 LNG Infrastructure in Africa

African market review is showing positive prospects for natural gas and the region has been poised to transform the global energy landscape. New gas discoveries in Mozambique and Tanzania position Africa as a potential major supplier of natural gas producer led by Algeria, Nigeria, Angola, Egypt and Equatorial Guinea (BP, 2013, p53; Denton-Brown & Thomet, 2014, p1). However, in order to realise the potential, gas infrastructure is required to transport gas to the market. The following section provides an overview of current and planned infrastructure within the African region.

North Africa continues to dominate the regional production in a short term with Egypt recently commissioning an LNG plant at Idku which consists of two trains with each able to produce 3.6 MTPA. In addition, another LNG plant is scheduled to start producing 5 MTPA in 2015 at Damietta. Algeria, has also added two new LNG plants for exports at Arzew and Skikda which are producing over 9 MTPA (Denton-Brown & Thomet (2014, p7).

In Angola, Soyo LNG plant has recently started producing and will use associated gas resources mainly from shallow-water fields to deliver 5.2 million tons per year of LNG - plus natural gas, propane, butane and condensate (Department of Economic Development and Tourism [DEDT], 2013, p69; Denton-Brown & Thomet, 2014, p7). Further north in Equatorial Guinea, the Malabo plant has been producing since 2007 and has a capacity of 3.7 MTPA. The facility was commissioned in 2007 and there are plans to expand the capacity to the potential 4.4 MTPA (Denton-Brown & Thomet, 2014, p7). Equatorial Guinea has the potential to serve as a regional gas hub, providing the means to commercialise the large volumes of stranded natural gas offshore in Equatorial Guinea and other significant gas resources in the Gulf of Guinea (http://www.hydrocarbons-technology.com/projects/bioko-lng/).

Nigeria has potential to compete with the leading LNG producing countries with the addition of Brass Island facility which will have a capacity of 9.9 MTPA and start producing in 2015 (DEDT, 2013, p68; Denton-Brown & Thomet, 2014, p6). In East Africa large offshore gas fields have been discovered near the common border of Tanzania and Mozambique. Mozambique reserves have been estimated at 160 trillion cubic metres while Tanzania is estimated at 20 trillion cubic feet (DEDT, 2013, p68). In response to these opportunities, LNG projects are already underway in both Mozambique and Tanzania (Denton-Brown & Thomet, 2014, p6).

3.2 Gas Infrastructure in South Africa

The following section highlights the existing natural gas infrastructure with responsible stakeholders in South Africa. Additionally, this section will also provide an overview of future natural gas infrastructure development plans at a national level. In particular, the proposed development scenarios of LNG import terminals will be the key to the objective of this study. It must be noted at this point that national future development plan scenarios outlined herewith will underpin the establishment of an LNG bunkering supply chain by South African.

a) Sasol Gas

Sasol Limited is an integrated energy and chemical company whose business includes development and commercialisation technologies, including synthetic fuels technologies, and produces different liquid fuels, chemicals and electricity (http://www.sasol.co.za/about-sasol/south-african-energy-cluster). Sasol Gas owns and operates a high pressure pipeline through a joint venture with the Republic of Mozambique Pipeline Company (ROMPCO), and the state owned South African company iGas. The pipeline transports gas produced from gas fields in the vicinity of Vilancoulus in Mozambique (Temane and Pande gas fields) to Secunda in South Africa where the gas is delivered into the gas transmission and distribution pipeline network owned and operated by Sasol (http://www.sasol.co.za/about-sasol/south-african-energy-cluster). The pipeline has a total length of approximately 865 km with 240 million gigajoules (GJ) per annum capacity (PWC, 2012, p12).

From the distribution pipeline, Sasol supplies gas to commercial and industrial customers via a pipeline network covering more than 2 000km in the Free State, Gauteng, Mpumalanga and KwaZulu-Natal (PWC, 2012, p12). In Gauteng, Sasol serves about 600 mainly industrial customers including Egoli Gas, a reticulator supplying piped gas in the Greater Johannesburg metropolitan area, which serves a mix of industrial, commercial, and domestic customers (DME, 2005, p32).

The company operates Sasol 1 plant in Sasolburg which produces hydrogen rich gas and Sasol 2 and 3 plants at Secunda for methane rich gas. Hydrogen rich gas is supplied to Gauteng and the methane rich gas to Witbank and Middleburg in Mpumalanga and via the Transnet Pipeline named Lilly pipeline to Kwazulu Natal (Newcastle, Richard’s Bay and Durban) – (Figure 3.1) (DME, 2005, p32).

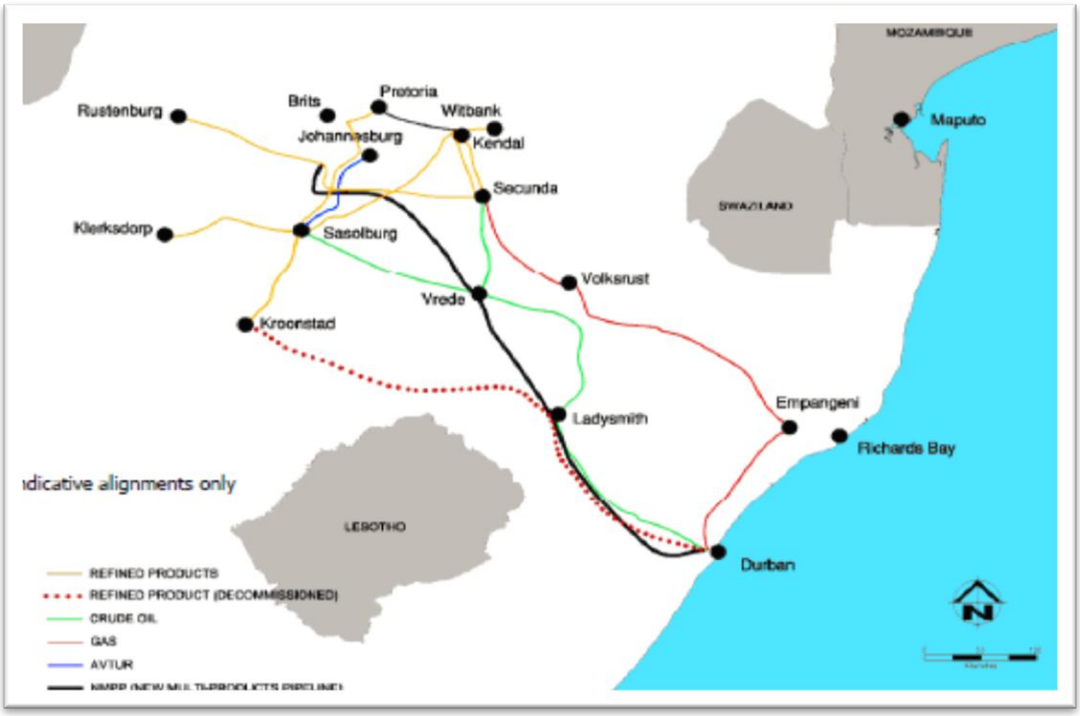


Figure 3.1: National pipeline network (Source: Transnet Pipelines, 2009)

The facilities owned by ROMPCO include the pipeline, a compressor station at Komatipoort, a pressure protection station situated in Secunda. ROMPCO is currently busy constructing a 128 km loop line from the gas field at Vilancoulus that will connect into the pipeline and will increase the capacity of the pipeline. Construction is expected to be finalised in 2014. Further capacity expansions by means of loop lines and/or compressor stations are planned and will be developed to suit gas availability and demand (http://www.sasol.co.za/about-sasol/south-african-energy-cluster/sasol-gas/rompco/overview).

b) Egoli Gas

Egoli's origins are as a town gas producer distributing through its own pipes in the Johannesburg area. It no longer produces its own gas but buys from Sasol to service more than 7500 domestic, central water heating, commercial and industrial businesses in the Johannesburg area. For domestic use, Egoli Gas is located in many of the more established Johannesburg suburbs; however, the pipeline extends even further to commercial and industrial customers (http://www.egoligas.co.za/about-us.html.). The company has a 1 300 km distribution pipeline operating at <1-bar gauge pressure. Egoli allows for swings in demand by means of storage and interruptible customers (DME, 2005, p33).

c) Transnet Pipelines

Transnet pipeline (TP) is a division of the Transnet state owned company which provides transport services for gas, crude oil, aviation turbine fuel, diesel, alcohol and various grades of petrol over varying distances using over 3 000 km of high pressure pipelines (DME, 2005, p33). It handles an annual average throughput of some 16 billion litres of liquid fuel and more than 450 million cubic metres of gases. The pipeline is known as the Lilly Line and is approximately 600 km long (Figure 3.1) and transports methane rich gas from Sasol's Secunda plant to Durban via Empangeni (DME, 2005, p33).

d) PetroSA's GTL facility

Petros SA is a state owned company operating the world's first commercial GTL facility using feed gas from offshore gas fields south of Mossel Bay (Figure 3.2). The gas is delivered to the GTL refinery via a subsea pipeline that runs northwards through Vleesbaai, making landfall at Nautilus Bay and from there runs underground in a PetroSA pipeline servitude to the refinery (CSIR, 2013, p1-2).

The natural gas production in South Africa is from the 20 billion cubic metres F-A field located in Block 9 of the Bredasdorp basin in 105 metres of water depth some

93 km offshore of Mossel Bay. Gas is dried and refrigerated at the platform and transported to the PetroSA synfuel facility through an 18-inch pipeline. Condensate is transported through an 8-inch pipeline after separation offshore. The whole output of this operation is dedicated to the government-owned PetroSA GTL plant (DME, 2005, p33). However, the available resources at the Bredasdorp basin are near depletion and have affected operations of PetroSA's GTL facility (DOE, 2013, p39). In an effort to keep the facility going, PetroSA is exploring undeveloped discoveries of gas from F-O field in the central Bredasdorp basin to supplement the current supply of feedstock to 2019/20 (DEDT, 2013, p59). Moreover, the company is also looking at the import of LNG to the facility through a terminal near Mossel Bay to secure long term gas supply (DME, 2005, p34; DEDT, 2013, p59).

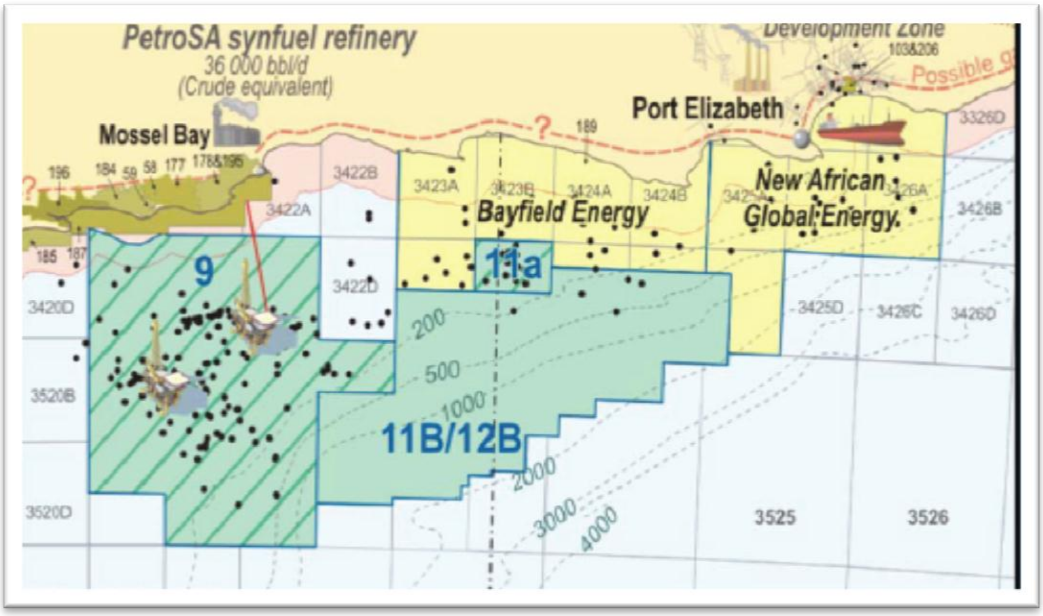


Figure 3.2: Petroleum exploration (Source: PWC, 2012)

e) Transnet National Ports Authority (TNPA)

TNPA is a division of Transnet responsible for safe, effective and efficient economic functioning of the national port system, which it manages in a landlord capacity. The national ports authority provides port infrastructure and marine services at the eight commercial seaports in South Africa. Namely, Richards Bay, Durban, East London, Ngqura, Port Elizabeth, Port of Ngqura, Mossel Bay, Cape Town and Saldanha (http://www.transnet.net/Divisions/NPAuthority.aspx).

Some of the key responsibilities for TNPA include the development of port infrastructure and provision of maritime services. Maritime services include dredging, aids to navigation, ship repairs and marine operations. Port infrastructure is provided in five commodity sectors which include liquid bulk such as petroleum products, chemicals, vegetable oils (http://www.transnet.net/Divisions/NPAuthority.aspx). However, the port system does not make provision for handling natural gas or LNG. The port authority has acknowledged the need and plans to commission a feasibility study for the LNG import terminal in Saldanha, Ngqura and Richards Bay (Transnet, 2013, p155).

3.3 LNG Demand in South Africa

Demand for LNG is currently constrained by a number of challenges including lack of bunkering infrastructure and large volumes required to make LNG infrastructure feasible. South African Integrated Resource Plan, rev.2 (IRP2) acknowledges the identified challenges and in response makes provision for gas-fired power generation to stimulate demand and consumption for LNG. Gas-fired power generation requires large volumes of natural gas which South Africa will need to import as LNG due to limited local reserves. It is expected that this will then unlock development of the LNG supply chain including import terminals, storage and distribution infrastructure. The following discussion provides an overview of the land based LNG demand and the potential demand for LNG marine fuel. Thereafter, the anticipated demand will be used to inform the proposed LNG bunkering infrastructure supply chain in SA.

3.3.1 Land based Demand

As mentioned earlier, South Africa has abundant shale gas resources that are technically recoverable. However, shale gas is currently a sensitive matter under discussion to address identified environmental concerns and is not available to the market. Hence, the need to import natural gas as LNG in order to realise the objective for energy mix as set out by the Department of Energy. Land based demand was based on Western Cape natural gas importation study and two planning scenarios identified in the Transnet Long-term Planning Framework (LTDF) of 2013 as outlined in this section. Transnet is a State Owned Company which operates as a corporate entity. The Transnet group consists of five core operating divisions which include but not limited to Transnet Pipelines and TNPA. These two divisions are specifically mentioned because they are critical to the development of the gas pipeline infrastructure and LNG import terminals respectively.

3.3.1.1 Market demand infrastructure driven scenario

This scenario was based on existing gas infrastructure supplying South Africa with natural gas from Mozambique to the Sasol refinery. From the distribution pipeline, Sasol supplies a number of commercial and industrial customers via a pipeline network covering the Free State, Gauteng, Mpumalanga and KwaZulu-Natal. Given this existing demand, it is therefore logical to stimulate further potential natural gas demand through infrastructure led market development. The concept of infrastructure led market development has been demonstrated in the US and other international economies for natural gas and it shows that supply and infrastructure needs lead and demand follows.

The proposed scenario for infrastructure led demand is illustrated in Figure 3.3 which shows the geographical location and the conceptual framework. In this case, the existing supply and South African gas infrastructure highlighted earlier are used to unlock potential demand and trigger a need for additional supply and consequently the development of infrastructure required to meet the demand. Transnet anticipates that growth in natural gas consumption will create momentum for more demand.

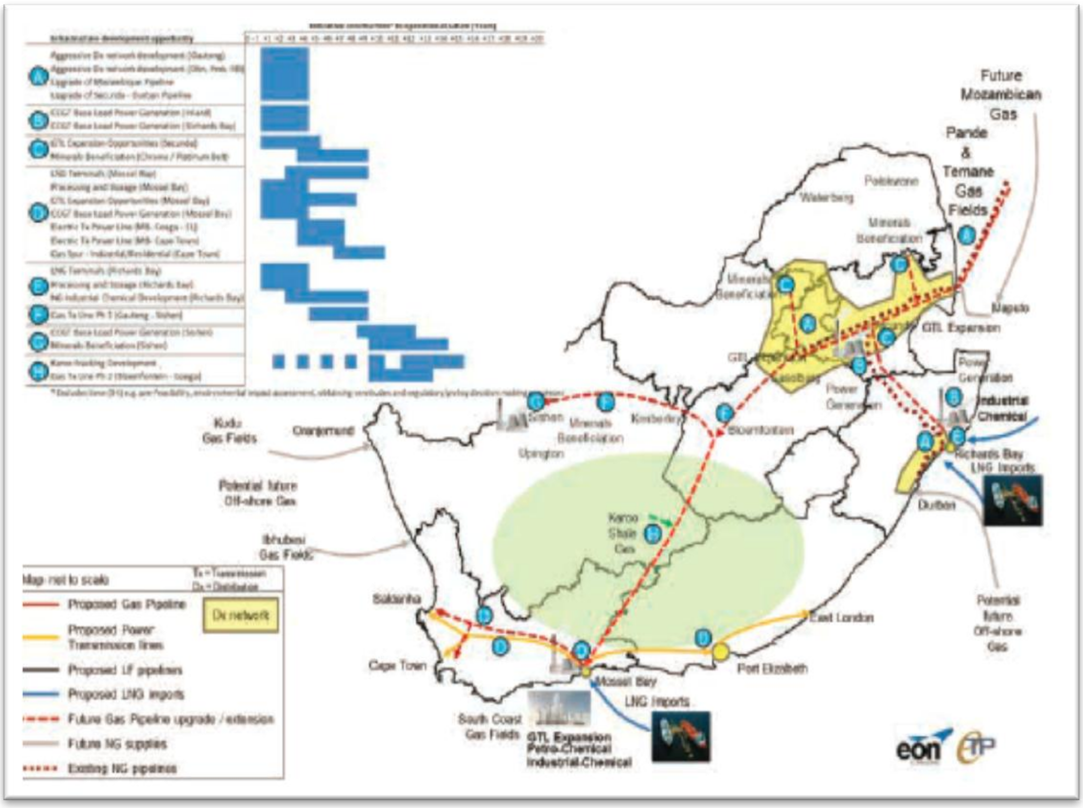


Figure 3.3: Geographical illustration of Market Demand infrastructure driven scenario (Source: Transnet, 2013)

Furthermore, Transnet made a number of assumptions highlighted herewith together with the proposed infrastructure to inform this scenario.

- Market potential – power generation and GTL capabilities in South Africa will ensure sufficient demand to make gas infrastructure viable. In addition, there is potential for increased demand from industrial, commercial and gas energy intensive mineral beneficiation.
- Natural gas supply – Mozambique is currently supplying South African through an existing pipeline. However, it is expected that this supply will not

be adequate and therefore natural gas will need to be imported from some of potential suppliers identified in Figure 3.4.

- Gas infrastructure – firstly, Transnet proposes an aggressive natural gas distribution based on the existing supply pipeline to both Gauteng and the East Coast (Lilly line), including expansion of network to supply industrial, commercial and household customers. Additionally, the expansion from the initial phase can include the development of a transmission pipeline to the Northern Cape to enable minerals beneficiation potential and base load power generation. The second phase expansion to Coega in the Eastern Cape may also be required should the Karoo shale gas turn out to be viable and productive.

Secondly, Transnet anticipates that Mozambique pipeline supply will not be adequate, and proposes the development of LNG import and storage capabilities in Richardsbay to ensure security of supply. In addition, a similar facility is also recommended in Mossel Bay to sustain GTL refinery.

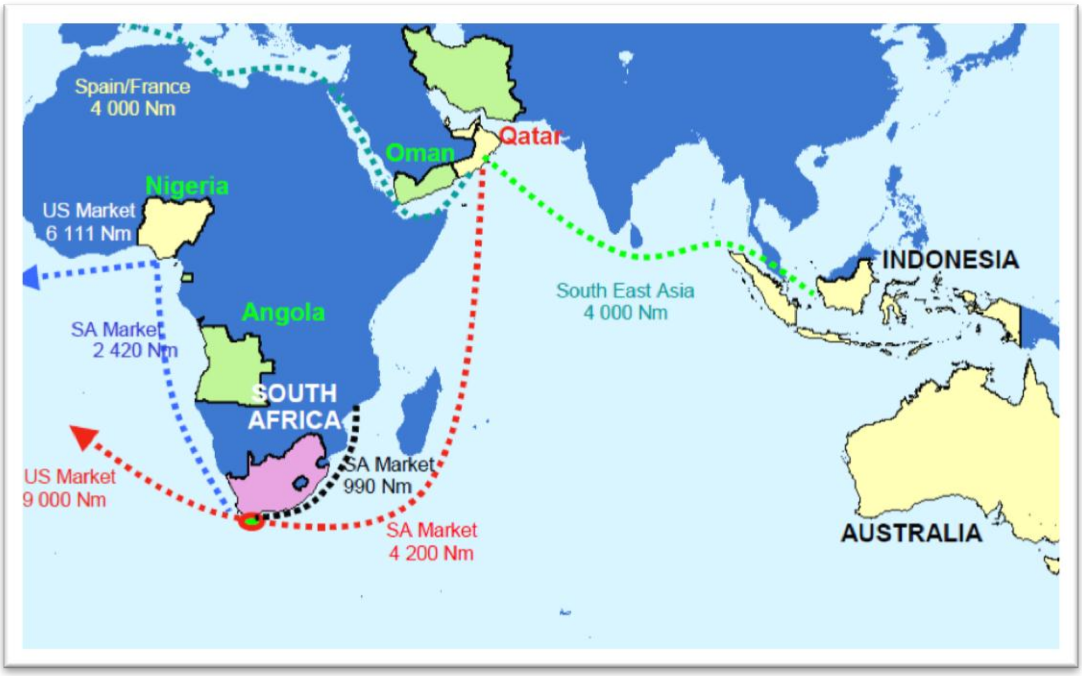


Figure 3.4: Geographic location of potential suppliers (Source: DEDT, 2013)

3.3.1.2 Economic development policy infrastructure driven scenario

From an economic development perspective, the South African government has identified East Cape as a key area for development and this was informed by the Presidential Infrastructure Coordinating Commission (PICC). Inevitably, such economic development will require matching energy supplies in order to be sustainable.

The proposed scenario for economic development policy infrastructure is illustrated in Figure 3.5 which shows the geographical location and the conceptual framework. This scenario was based on a number of assumptions highlighted herewith together with the proposed infrastructure.

- Market potential – base load power generation is proposed at Coega for the project to be viable. Coega Development Corporation (CDC) has also identified minerals beneficiation as one of the key investment opportunities. Mineral beneficiation in Northern Cape may also be connected through a potential transmission pipeline linking Coega and Gauteng.
- Potential supply – a number of potential natural gas and LNG suppliers have been identified as illustrated in Figure 3.4.
- Gas infrastructure – Transnet is proposing the development of an LNG import terminal at Coega to stimulate further developments. The facility will then be linked to Mossel Bay to sustain GTL production. The Transnet plan also identifies potential to develop natural gas transmission pipeline from Coega to Gauteng to ensure long-term sustainability of natural gas as an energy source in South Africa.

Moreover, once the issues regarding Karoo shale gas are resolved and production becomes viable, it will feed into the established natural gas pipeline and supply various production sites. The pipeline will become a backbone of natural gas supply to other areas inland as well as Durban, Richards Bay and possibly Saldanha and Cape Town.

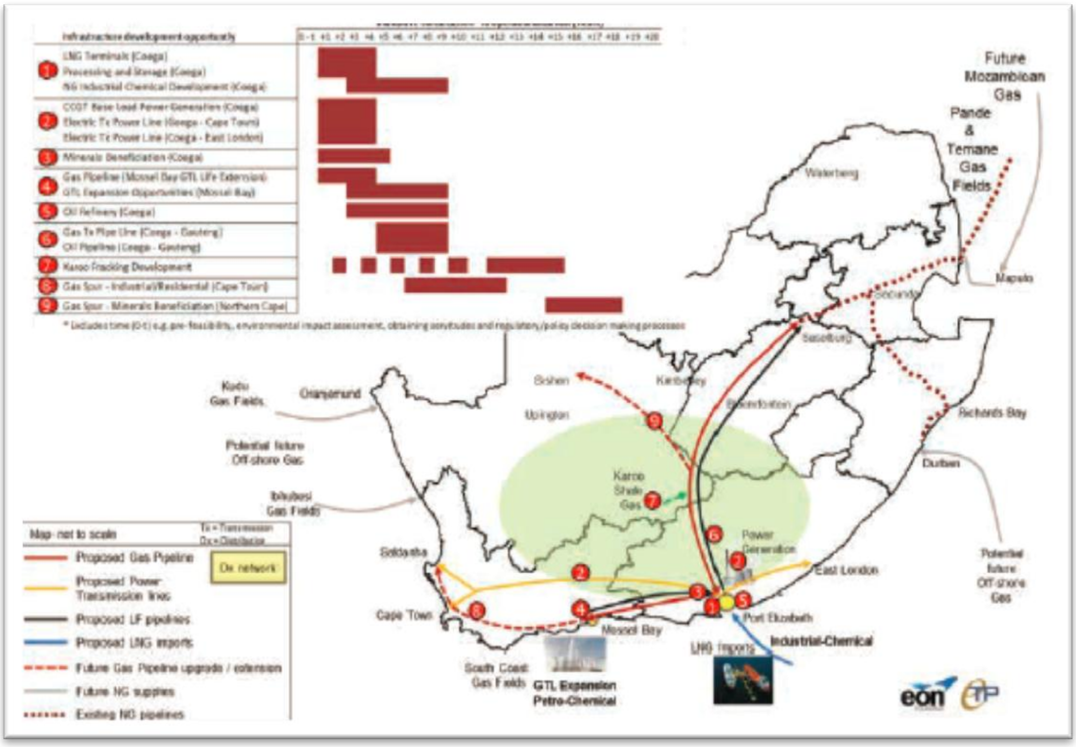


Figure 3.5: Geographic illustration of Economic Development Policy infrastructure driven scenario (Source: Transnet, 2013)

3.3.1.3 Western Cape natural gas importation scenario

A pre-feasibility study was commissioned by the Department of Economic Development and Tourism (DEDT) for importation of natural gas to the Western Cape. The study was initiated in an effort to seek alternative energy source and stimulate industrial growth and the required employment opportunities in the province. The following summary provides an overview of the report (DEDT, 2013, p19-23).

The analysis conducted showed that the primary energy feedstock currently used by the industry was totally reliant on imported coal, fuel oil, LPG and diesel. In addition, the province is largely dependent on importation for electricity supply without alternative energy/electricity for industrial growth. Therefore, the study investigated natural gas with a focus to provide an alternative energy source and power generation. A number of factors were identified to assess technical commercial viability and they are highlighted below:

- Gas market potential in the Cape West Coast region – the assessment concluded that gas-fired power generation is a key driver to make gas importation options evaluation feasible.
- Potential natural gas supply sources – the review concluded that it is most viable to import natural gas as LNG from Nigeria, Angola and potentially Mozambique.
- Gas infrastructure requirements – the review identified the port of Saldanha or Yzerfontein/Duynefontein as alternative locations for the establishment of an LNG import terminal. The option for Yzerfontein/Duynefontein includes the establishment of Floating Storage and Regasification Unit (FSRU) together with the transmission and distribution gas pipeline networks for both options (Figure 3.6). FSRU was identified as a preferred option due to the shortest lead time for making first commercial gas available at lowest capital cost requirements.

The study concluded that natural gas importation will provide an alternative energy source within the region and relieve the dependence on importation of electricity. In addition, it was established that natural gas is price competitive compared to other sources of energy; however, the gas-fired generation is required to enable the development of the LNG import terminal.

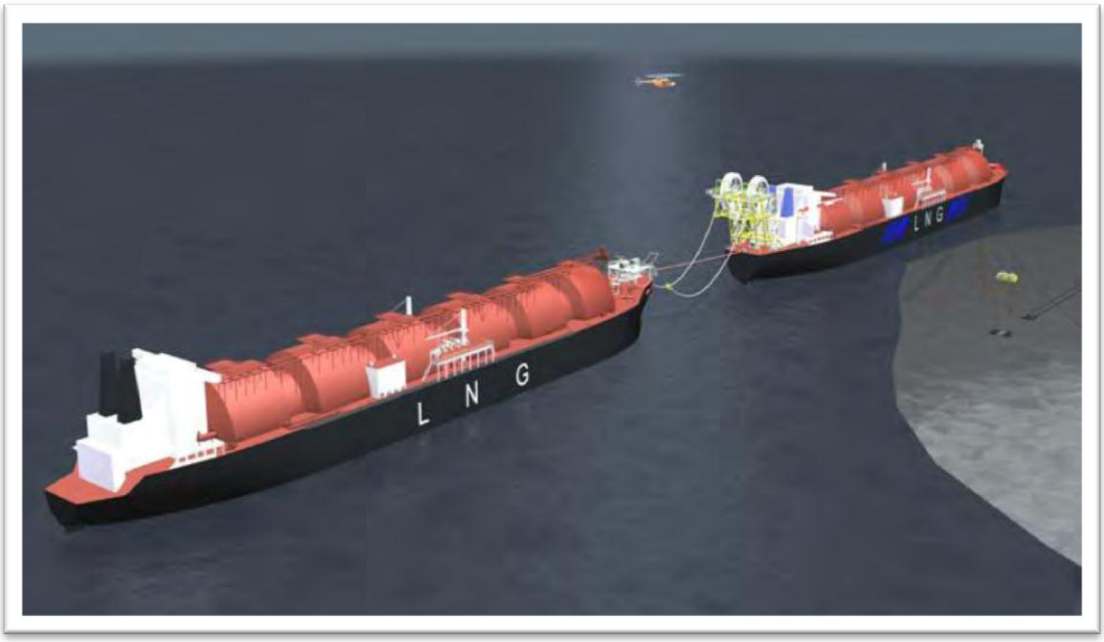


Figure 3.6: Floating Storage and Regasification Unit (Source: DEDT, 2013)

3.3.2 LNG Demand as Marine Fuel

LNG has been proved to be technically viable marine fuel for commercial ships. Key driving factors for using LNG marine fuel were detailed in Chapter 2 from a global perspective. The following section highlights critical driving factors for LNG demand as maritime fuel from a South African context.

As mentioned earlier, LNG infrastructure requires large volumes to justify commercial viability. South Africa has already identified that the main anchor consumers in power generation and refinery feedstock and both facilities require large volumes and thereby justify the investment in LNG import terminals. Furthermore, the abundance of shale gas available in South Africa presents a potential opportunity to be explored for energy supply in the event that pending issues are resolved.

These opportunities stimulate a growing interest in LNG as maritime fuel within the shipping industry, and in particular deep sea vessels calling in SA ports or passing through SA waters. The abundance of shale gas resources if realized and the provision of LNG import infrastructure position SA as a potential strategic LNG bunkering hub given its geographical location within one of the main shipping routes. In addition, the Department of Energy (2013, p29) has raised concerns that transportation in South African waters is heavily dependent on petroleum liquids, thereby making it vulnerable to the availability and cost of oil. The department strongly recommends diversification to include other sources of energy such as natural gas in order to improve security of supply and minimise environmental impact (DOE, 2013, p32).

Details of environmental key drivers for using LNG as maritime fuel are provided in Chapter 2 from a global perspective in line with IMO regulatory requirements. In a South African context, MARPOL Annex VI sets out stringent requirements for ECA’s which are currently established in the Baltic Sea, the North Sea and North America. However, ECAs will be expanding further to other countries which may include the South African region in the near future. Annex VI has also established global limits applicable to all areas such as SOx 3.5% maximum emissions from marine fuels. SOx limit is said to be reduced further down to 0.5% between 2020 and 2025 following a review to be conducted in 2018. Therefore, it is expected that implementation of global limits will accelerate the adoption of LNG as marine fuel worldwide including areas currently not designated as ECA like South Africa (Figure 3.7).

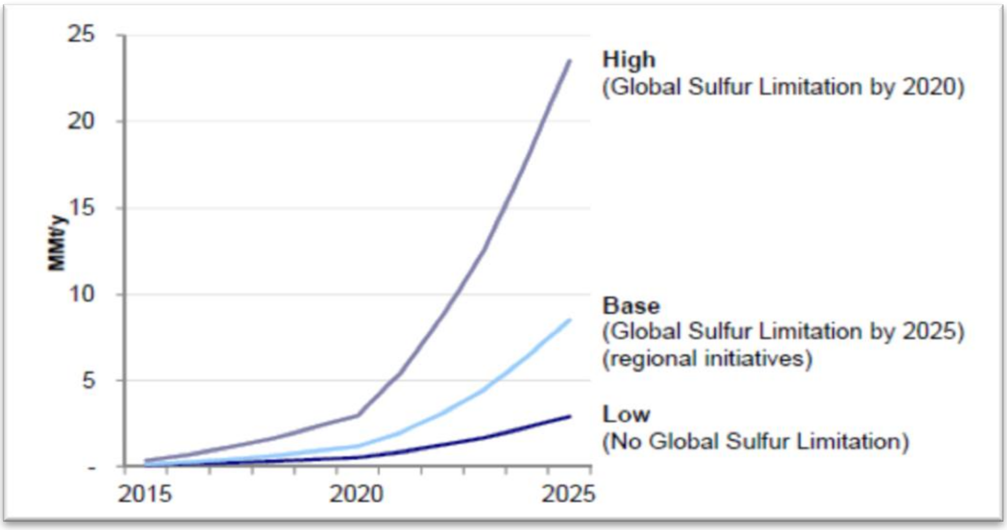


Figure 3.7: Projected LNG fuel demand impacted by Annex VI
Source: Adamchak and Adebe, 2013

Moreover, a survey was conducted by Lloyds Register to establish ship owners' view of their deep-sea bunkering locations along the main trade routes (Aagesen, 2012, p5). From a South African perspective, it was noted that Cape Town and Durban are included in the top ten primary bunkering locations as indicated in Figure 3.8. This finding reaffirms potential for LNG demand as marine fuel in South Africa as it is well positioned within one of the main trading routes.

Lloyds Register study also concluded that there is a direct correlation between the location of primary bunkering hubs and the main shipping trade lanes. Also LNG import and export terminals are located either at these bunkering locations or close to them therefore allowing for the supply of LNG to the primary bunkering hubs (Aagesen, 2012, p5). In view of the proposed LNG import facilities for South Africa, a final decision on their location in relation to Cape Town and Durban has potential to stimulate demand of LNG as marine fuel.

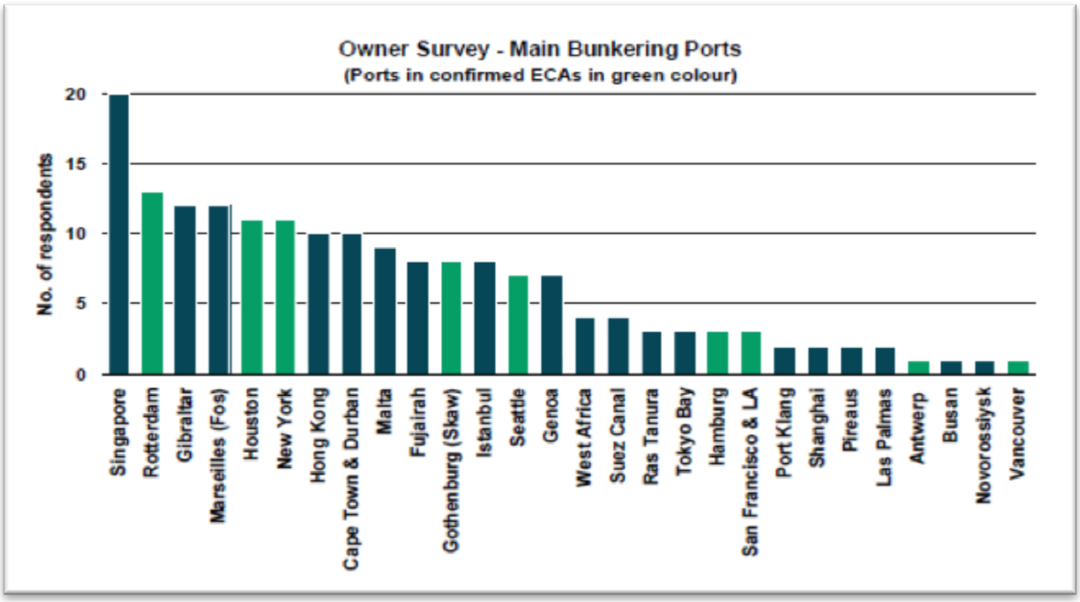


Figure 3.8: Primary bunkering locations from ship owner survey
(Source: Aegesen, 2012)

Furthermore, the survey also indicated that LNG and dual-fuel engines are a long-term objective mostly for containership and cruise ship owners (Aegesen, 2012, p7). This point is particularly important for Durban and Cape Town ports considering a number of container vessels and cruise ships calling at both ports. In addition, Figure 3.9 provides an indication of trends on the development of LNG fuelled fleet and shows that the delivery is picking up in 2014 with significant projected increase. This will also contribute to the demand of LNG as marine fuel.

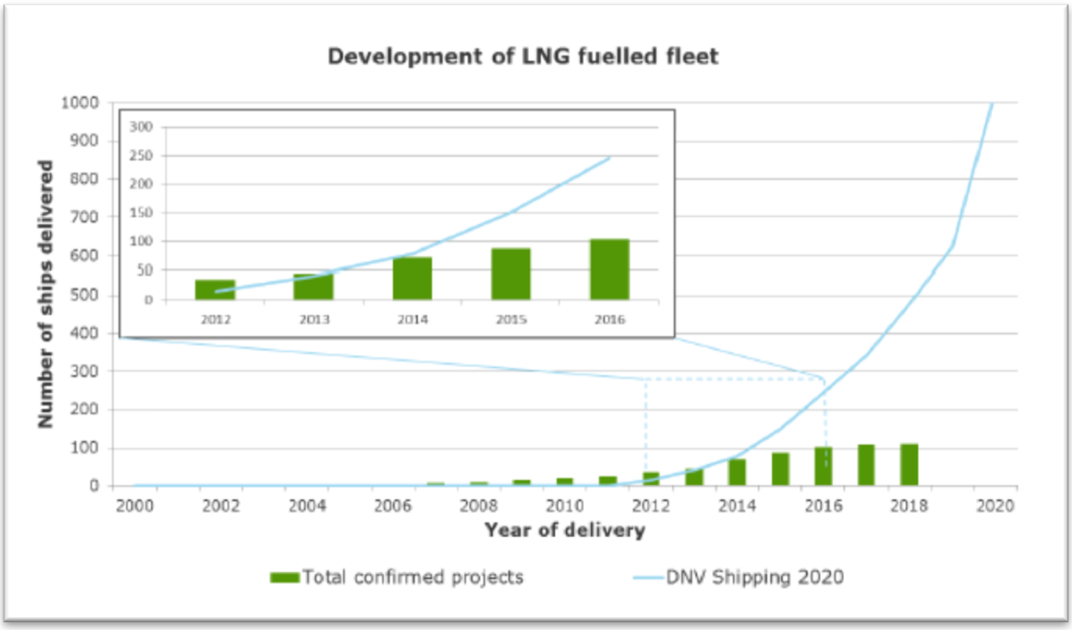


Figure 3.9: Development of LNG fuelled ship fleet (Source: Wuersig, 2014)

3.4 Supply Chain

South African ports are managed by Transnet National Ports Authority whose responsibility is to ensure safe, effective and efficient economic functioning of the eight commercial ports in a landlord capacity. Consequently, port services such as bunkering operations are carried out by third parties; however, *National Ports Act 2005 (Act No. 12 of 2005)* provides a regulatory framework for managing such services. Therefore, ports are considered to be critical enablers for the development of LNG bunkering operations. The following discussion provides an overview of the upstream supply chain and proposes a downstream supply for LNG marine fuel within the context of presented cases for an LNG import terminal.

3.4.1 Upstream LNG Supply Chain

According to Transnet LTDF 2013, the port of Richardsbay and Mossel Bay versus the port of Ngqura have been identified as potential locations for LNG import terminals based on different cases presented earlier for land based demand. LTDF also identifies the port of Saldanha as a potential location for LNG import; however, it was excluded on initial plans but it will be included in a planned feasibility study by TNPA. The option for the port of Saldanha and an FSRU between Yzerfontein and Duynefontein was also identified in a separate pre-feasibility study conducted by Western Cape government for importation of natural gas (DEDT, 2013, p79). All these cases have their own merits to justify the investment for the development of LNG import terminal to cater for the last part of the upstream LNG supply chain as illustrated in Figure 3.10. A number of potential LNG supplies who cater for exploration, production and liquefaction have been identified in Figure 3.4 for import through shipping to complete the upstream supply chain part.

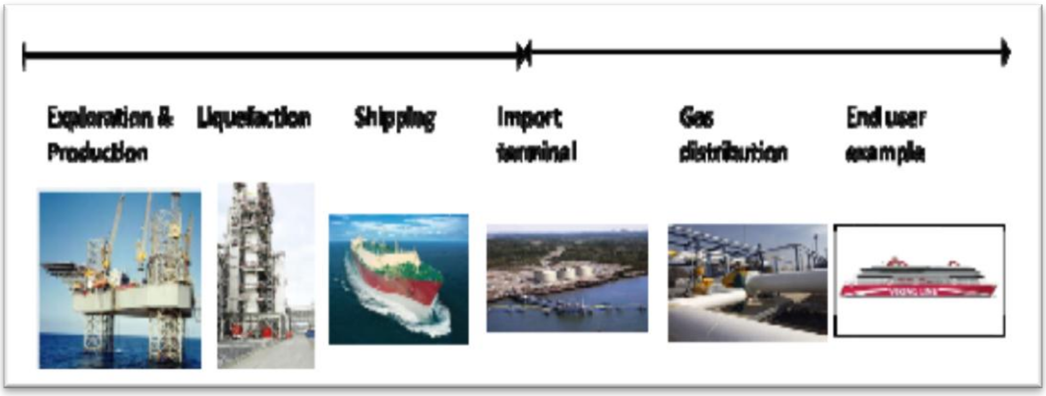


Figure 3.10: LNG Supply Chain (Source: DMA, 2012)

Therefore, all the options for LNG import infrastructure set the basis for downstream expansion to establish LNG bunkering stations as proposed in the next part. For the purpose of the discussion the first option based on market demand will be called planning option A, the second option based on economic development policy – planning option B and the Western Cape study – planning option C.

3.4.2 Downstream LNG Supply Chain

The following section outlines a proposed downstream supply chain for LNG as marine fuel for all planning scenarios with consideration to Durban and Cape Town as primary bunkering hubs. The development of the downstream supply chain entails handling of small LNG volumes compared to the import terminals. To facilitate the discussion, the scales mentioned herewith are defined in Table 3.1 to put them into perspective.

Table 3.1: Volume scale definitions (Source: DMA, 2012)

Activity/Aspect	Large scale	Medium scale	Small scale
On shore storage capacity	Import terminal ≥100,000m³	Intermediary terminal 10,000-100,000m³	Intermediary terminal <10,000m³
Ship size LNG capacity	LNG carriers 100,000-270000m³	LNG feeder vessels 10,000-100,000m³	LNG bunker vessels 1,000-10,000m³; LNG bunker vessels/barges 200-1,000m³
Tank trucks			40-80m³

The most characteristic items for required infrastructure are the tank sizes, size/number of bunkering vessels used, capacity utilization and throughput. It should be noted that the large case terminal has no separate storage tank since it is located in a port where LNG is imported and hence the maritime supply infrastructure can connect to that tank (DMA, 2013, p100). This set up was taken from DMA North Europe LNG infrastructure report to guide the discussion and characterise the supply chain proposed below.

3.4.2.1 Planning Option A

The first scenario was based on the market demand infrastructure driven development and the conceptual framework is provided in Figure 3.3. This option proposes the development of LNG import and storage facilities in Mossel Bay and Richardsbay. Assuming that this scenario materialises and is implemented based on the supporting arguments highlighted earlier, the two LNG terminals will then lay down a baseline for the downstream LNG supply chain for marine fuel.

Firstly, the LNG facility in Richards Bay will be able provide bunkers to LNG vessels calling directly at the port either through a terminal to ship pipeline and LNG trucks. Since the port of Durban has been targeted as a bunker hub, it is anticipated that demand may be low in Richardsbay and therefore a terminal to ship pipeline and a tanker truck will suffice. The bulk of LNG marine fuel will therefore be supplied to the port of Durban through a feeder vessel which may also be used as a bunker vessel in Richardsbay on adhoc basis when required. Alternatively, the distance from Richards Bay to Durban (180km) allows for the construction of a pipeline to supply Durban. However, since LNG will be regasified for local distribution through a pipeline, it will require a liquefaction plant to convert received gas back into LNG for supply to vessels in Durban. Otherwise, a long distance cryogenic pipeline will need to be developed for direct transportation to Durban. Neal et al., (2005) indicate that operation and maintenance of such pipelines is often very costly. Therefore, pipeline transportation will significantly increase supply chain infrastructure costs and ultimately the LNG prices and result in loss of demand; hence, a feeder vessel is recommended.

The port of Durban will need to provide medium scale intermediary LNG terminal for LNG transported through feeder vessels and pipelines to supply LNG fuelled vessels. The same feeder/bunker vessel can be based in Durban for ship to ship bunkering in addition to a terminal to ship pipelines to meet potential demand. As the demand grows, a bunker barge may be added in the short term until the demand justifies another bunker/feeder vessel. LNG truck may also be used for distribution of small quantities required within the port to allow flexibility.

Secondly, LNG facility proposed in Mossel Bay is located equidistance between Port Elizabeth and Cape Town. Port Elizabeth is home to two ports named the port of Port Elizabeth and the port of Ngqura and the latter has been positioned as transhipment hub for containers. As noted earlier, container vessels are the off takers for LNG marine fuel and therefore it is anticipated that deep sea LNG fuelled container vessels calling at Ngqura may require supply. The port of Mossel Bay is the smallest commercial port within TNPA and demand for LNG for marine fuel would be limited; therefore, the LNG terminal in Mossel Bay would serve as a supplier to the port of Cape Town and PE ports. With consideration to potential demand for Port Elizabeth ports and the distance of approximately 400km, supply through an LNG truck is recommended in the short term until demand justifies a feeder/bunker vessel and a small scale intermediary terminal.

On the other hand, the port of Cape will need supply through a feeder/bunker vessel as the target bunkering hub. In addition, a medium scale intermediary LNG terminal will be required for storage of products received from Mossel Bay and pipelines for direct supply to the LNG fuelled vessels. Feeder/bunker vessel may also be used for ship to ship bunkering within the port to meet the demand. LNG truck may be used for distribution of small quantities required within the port to allow flexibility. Figure 3.11 provide an overview of the proposed logistics chain and indicate distance and sailing days from import terminal to identified bunker ports.

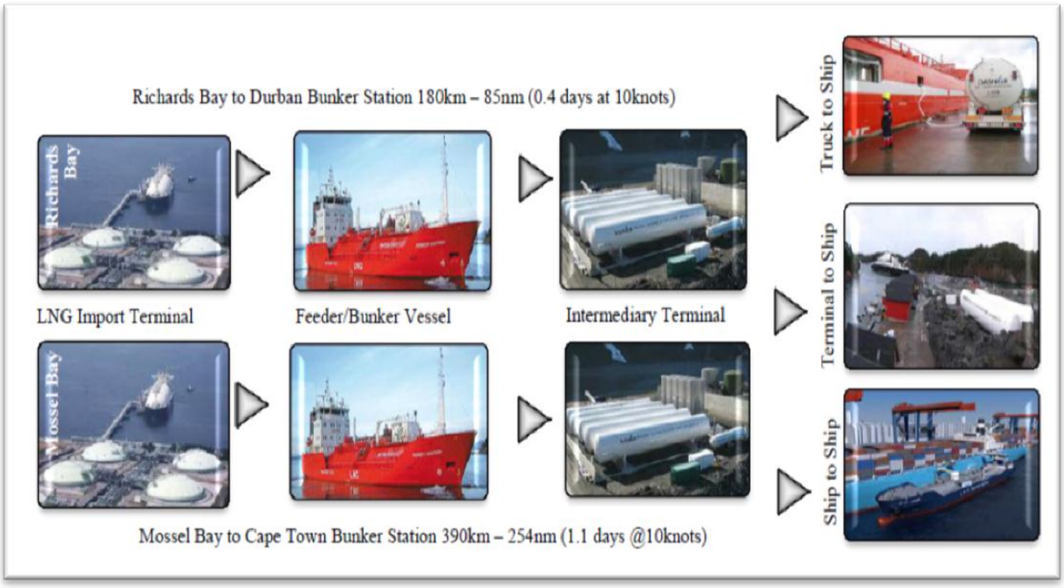


Figure 3.11: LNG supply chain – Planning option A

3.4.2.2 Planning Option B

The second scenario was based on the economic development policy infrastructure perspective and the conceptual framework is provided in Figure 3.5. This option proposes the development of an LNG import terminal and storage facilities in Port Elizabeth. Assuming that this scenario materialises and is implemented based on the supporting arguments highlighted earlier, LNG terminals will then lay down a baseline for the downstream LNG supply chain for marine fuel.

As mentioned, Port Elizabeth is home to two ports and the proposed import terminal will be located at the port of Ngqura. Only limited demand has been anticipated in Port Elizabeth; therefore, the bulk of LNG allocated for marine fuel will need to be transported to the two target bunkering hubs i.e. the port of Cape Town and the port of Durban. Similar to the first case, both Durban and Cape Town will serve as medium scale intermediary LNG terminals and will therefore require supply from Ngqura through a feeder/bunker vessel from PE. Supply pipelines will also be required in each port for direct filling of LNG fuelled vessels. One feeder/bunker vessel for Cape Town and Durban will be required and it may also be used for ship to ship bunkering. As the demand grows, a bunker barge may be added in the short term until the demand justifies another bunker/feeder vessel.

The distance from port Elizabeth to Cape Town is approximately 750km and to Durban its 850 km and therefore the use of trucks is regarded as economically not viable. LNG truck may only be used for distribution of small quantities required within the port to allow flexibility. Figure 3.12 provide an overview of the proposed logistics chain and indicate distance and sailing days from import terminal to identified bunker ports.

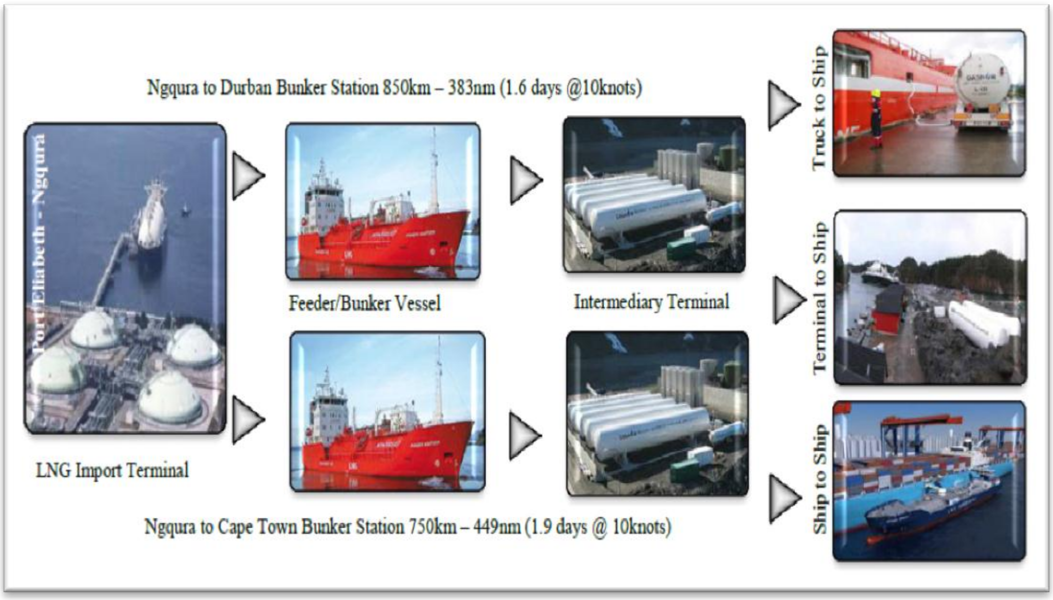


Figure 3.12: LNG supply chain – Planning option B

3.4.2.3 Planning Option C

Pre-feasibility study initiated by Western Cape government propose the development of LNG import terminal at the port of Saldanha or an offshore terminal (Floating Storage and Regasification Unit – FSRU) between Duynefontein and Yzerfontein based on the motivation highlighted earlier. If this proposal is accepted and implemented, the LNG import terminal will also provide a baseline for the downstream LNG supply chain for marine fuel.

Firstly, the proposed LNG facility in Saldanha will be able to provide bunkers for vessels calling at the port of Saldanha through a terminal to ship bunkering pipelines. However, if the terminal is in Yzerfontein/Duynefontein, a supply truck may be used for delivery to Saldanha and Cape Town given the short distance, but this may be a challenge as FSRU converts LNG to gas and delivers to a transmission pipeline for distribution on shore. Otherwise, a long distance subsea cryogenic pipeline will be required for transportation from FSRU directly to port Saldanha and Cape Town or onshore LNG storage tanks at Yzerfontein/Duynefontein for delivery via trucks. In addition, even if received gas is delivered directly to Saldanha or Cape Town through the proposed natural gas pipeline distribution network, a liquefaction plant will be required to convert back into LNG in order to supply vessels as marine fuel. Therefore, the pipeline transportation will significantly increase infrastructure costs for LNG as marine fuel. A feeder/bunker vessel is thus recommended to service both Saldanha and Cape Town; however, it should be based in the port of Cape Town and supply Saldanha as and when required with ship to ship bunkering.

Secondly, the port of Cape Town is located close to both Saldanha (150km) and Yzerfontein/Duynefontein (87km) and thus allows for easy transportation of LNG through a tanker truck and feeder/bunker vessel. A feeder/bunker vessel is recommended in this case to supply large volumes of LNG to the port of Cape Town as a target bunkering hub. A medium scale intermediary LNG terminal will also be required to meet the demand of a bunker hub in Cape Town. This will also include the supply pipeline for direct filling of LNG fuelled vessels. Feeder/bunker vessels may be used for ship to ship bunkering within the port. Tanker trucks may be used for small deliveries within the port.

Thirdly, assuming that this will be the only LNG import terminal in South Africa there will be a need to supply Port Elizabeth ports (875km), the port of Richardsbay (1879km) and most importantly the port of Durban (1720km). Therefore, considering the distance from Saldanha, intermediary LNG terminals will be required in Port Elizabeth (small scale) and Durban (medium scale). The Durban terminal capacity will need to be bigger to supply local demand for a bunker hub and potential demand in Richardsbay. A feeder vessel will also be required for transport of LNG to both Port Elizabeth and Durban. Richardsbay can be supplied from Durban through tanker trucks if the demand is low and a feeder/bunker vessel as the demand picks up. Figure 3.13 provide an overview of the proposed logistics chain and indicate distance and sailing days from import terminal to identified bunker ports.

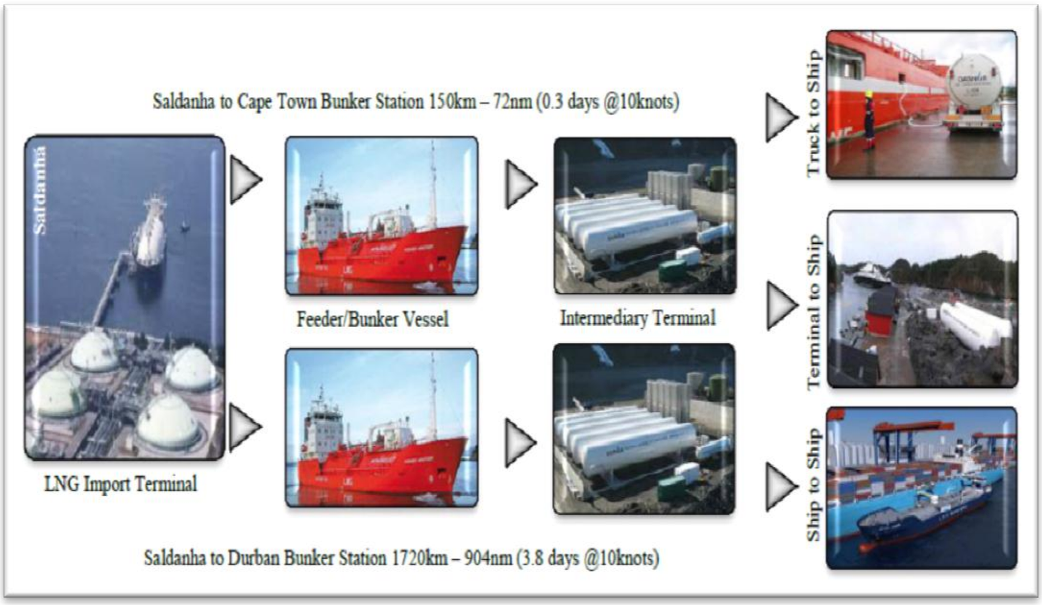


Figure 3.13: LNG supply chain – Planning option C

3.5 Bunkering Solutions

A number of bunkering methods (Figure 3.14) have been recommended above and they are explained in this part to highlight their functioning. Some of the key factors that were considered for recommended bunkering solutions include distance, traffic intensity, volume, vicinity to other LNG bunkering ports and land-based demand.

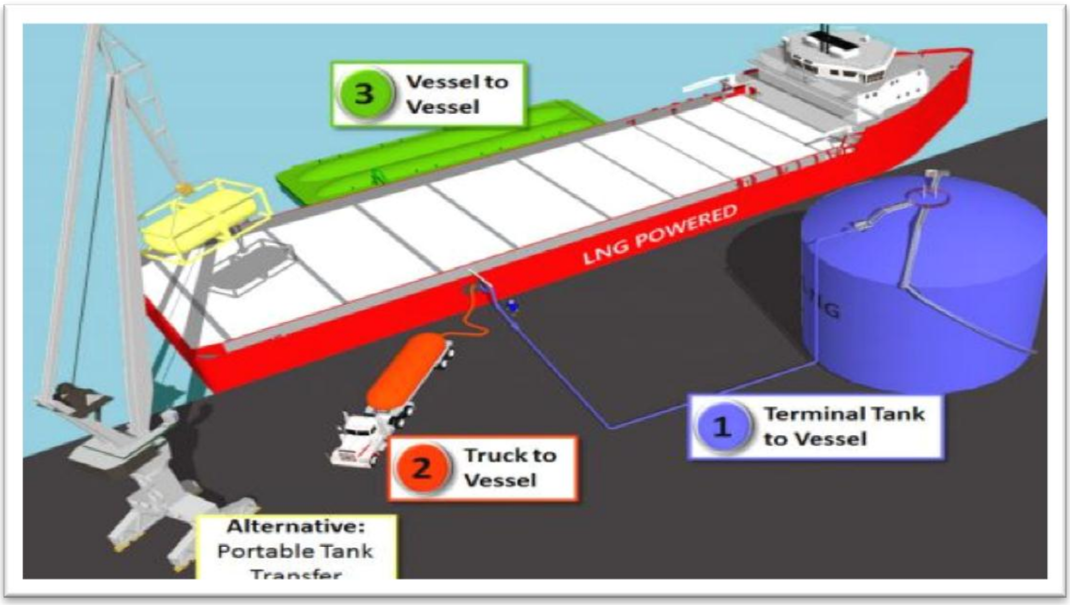


Figure 3.14: LNG Bunkering solutions (Source: ABS, 2014)

The following descriptions provide an overview of identified bunkering solutions (MPE, 2012, p4; DMA, 2012, p81; American Bureau of Shipping [ABS], 2014, p8):

- **Ship-to-ship (STS)** – this operations may be performed alongside quays. Although offshore bunkering is also possible, it is restricted by weather conditions. Considering the capacity of vessels, this method is suitable for large volumes.
- **Tank Truck to Ship (TTS)** – tank trucks provide a flexible method of bunkering for small volumes (up to 100-200 m^3) and it is inexpensive to invest in. The upper limit only holds if the turnaround time is long enough for bunkering activities, which require 3-4 truckloads. The trucks are loaded by means of a flexible hose or a fixed arm at a flow rate of 50 to 100 m^3 per hour and unloaded by means of a flexible hose at a typical flow rate of 50 m^3 per hour.
- **Terminal to ship via Pipeline (TPS)** – this method is tailor made for high loading rates and large volumes, which means that bunker times can be kept short. It is also more suitable for specialized solutions, e.g., high frequency

liner shipping services with short turnaround times and niche ports with high frequencies of low volume delivery sizes by, for instance, tugs, utility vessels and fishing boats.

3.6 Infrastructure Requirements

The supply chain proposed above makes reference to a large scale, medium scale and small scale terminals as characterized by Table 3.1. It is assumed that feasibility assessment for the development of large scale LNG import terminal will make provision for the required infrastructure of LNG bunkering for ships. Therefore, the following infrastructure analysis for LNG bunkering will only focus on the proposed development of medium scale intermediary terminals at the port of Durban and Cape Town as target bunker ports and will also exclude small scale terminals.

Infrastructure requirements for medium intermediary terminal were established by identifying the necessary items for the terminal to be functional. Table 3.2 indicates a list of the identified infrastructure items and the amount required for the proposed LNG facilities based on the medium and high demand assumptions presented under financial evaluation in the next chapter.

Table 3.2: Bunkering infrastructure items (Source: DMA, 2012)

Cost Items	Demand		Cost €	Economic life time
	Medium	High		
Landbased tanks				
20000m^3	1	1	40,000,000	40
Tanks trucks (50m^3) incl. filling station	1	2	800,000	40
Pipeline and manifold connected to tank	1	1	500,000	40
LNG infrastructure on jetty	1	1	15,000,000	40
Bunkering vessels				
3000 m^3	1	1	28,222,222	20

4000 m^3	0	1	31,619,781	20
Port facilities				
Jetty/quay	1	1	20,000,000	40
Administrative costs				
Application for the activities	1	1	270,000	
License costs	1	1	100,000	
Operation of LNG tank				
Operation of 20000m^3 (€/m^3 throughput)	1	1	1	
Operation of bunker vessel				
3000m^3	1	1	2,371,049	
4000m^3	0	1	2,547,065	
Operation of tank truck	1	2	40,000	
Operation of pipeline	1	1	50,000	
Maintenance	1	1	1,000,000	
Administrative personnel	1	1	900,000	
Total Capital Costs	104,522,222	136,942,003		
Total Operating Costs	4,731,049	7,318,114		

The above cost estimates were sourced from a DMA (2012) report and were used to determine financial feasibility of the proposed LNG bunker infrastructure supply chain for the port of Durban and Cape Town. Transport costs from the LNG import port to the intermediary terminal were excluded from this analysis; however, they must be noted. It is also noted that the highest investment costs are mainly for LNG tanks, bunkering vessels and jetties.

However, the cost for jetty/quay together with other service infrastructure (roads, water, electricity, dredging etc.) may be provided by TNPA based on its mandate as the land lord while the operator will pay rentals and other charges. Furthermore, it is expected that port specific assessment will be conducted by the interested investors for the implementation of the proposed supply chain in each port.

3.7 Discussion

It has been widely agreed that the costs of infrastructure for the LNG supply chain for marine fuel are a significant barrier to the widespread adoption of LNG as fuel. The proposed LNG import facilities outlined above cater for significant costs of the LNG upstream supply chain, thereby laying a baseline for downstream to enable LNG marine fuel as an alternative. The business case for each scenario has its own merits to justify the investment on the import terminal without reliance on LNG demand as marine fuel from the shipping industry. South Africa has an opportunity to take advantage and invest further from the proposed import facilities by providing LNG bunkering infrastructure. The benefits of using LNG as marine fuel have been detailed in this study and can be realised in South Africa. Furthermore, considering the current global challenges for adopting LNG as marine fuel, South Africa has the opportunity to be a key player in addressing the stalemate of “chicken and egg” situation on the required investment through TNPA. As noted in Transnet LTFP (2013, p288), “the nature of demand for natural gas supply and infrastructure needs lead and demand follow”.

However, it appears that there has been a fragmented planning between Transnet and Western Cape. Both, Transnet and Western Cape reports are dated 2013 and the latter focuses only on the region without considering national plans. While Transnet attempts to provide a national view, it has also not incorporated Western Cape plans within their planning and the implications are herewith evident. If the assumption that the LNG import facility in Western Cape will be the only one in South Africa is true, then it can be observed from the proposed supply chain that transportation of LNG from Saldanha to Port Elizabeth, Durban and Richardsbay will be complicated. The distance will significantly increase the supply costs and ultimately the price of LNG as marine fuel, thereby resulting in loss of demand. This point triggers and emphasises the need to have a holistic total view of the whole SA potential and requirements for LNG infrastructure.

CHAPTER 4 - FEASIBILITY ASSESSMENT

The following chapter aims to assess feasibility of the proposed LNG bunkering infrastructure from Chapter 3. The assessment will be conducted from an economical, safety and environmental point of view also taking into account the externalities related to LNG and traditional fuel. A SWOT analysis will be conducted to identify areas which may require further attention to enhance viability of LNG bunkering infrastructure development.

4.1 Financial Infrastructure Considerations

4.1.1 Creating a NPV Model to Analyse LNG Bunkering Infrastructure Investment

The NPV model was created using a number of prerequisite variables that were estimated for the purpose of this study as highlighted herewith. In view of the study aim, to make an investment analysis of the bunkering infrastructure, the future price of LNG was fixed in order to find annual profits and cash flows. This price was based on the average LNG price per tonne as projected by several literature sources and more recently BP Statistical Review of World Energy for 2014.

According to Smith (2014), 20.8% of 4800 vessels that called at the port of Durban were provided with IFO180 bunkers during 2013. The medium demand scenario was based on the assumption that this demand will shift to LNG marine fuel towards 2020 in preparation for the introduction of global SOx limits. A total number of 3980 and 2735 vessels visited the port of Durban and Cape Town respectively and include coastal and ocean going vessels. An average of 3358 vessel visits was established for each port and it was assumed that 20% of visiting vessels will require 671600 MT/yr (3358 visits*20%*1000 MT/ship) of LNG marine fuel in a medium demand case. A high demand case was estimated at 30% with 1,007,400 MT/yr (3358visits*30%*1000MT/vessel). Assumptions for both demand scenarios are summarised in Table 4.1.

Table 4.1: LNG demand scenarios

	Vessels calls	**Demand**	**Volume Required**
Medium Demand	3358	@ 20%	671 600 MT/yr
High Demand	3358	@ 30%	1007400 MT/yr

The high demand scenario was also based on global SOx limits in effect and introduction of new ECAs in other regions including the South African region. IBIA (International Bunker Industry Association) as quoted by Smith (2012) has reported that more than 200 vessels have been passing through SA since 2012 and it is assumed that some of the vessels will be stopping over for LNG bunkering once there is reliable supply of LNG at cheaper prices compared to other fuels. The estimated figures in Table 4.2 were rounded off to the next decimal for the purpose of further calculation and it was assumed that revenues and operating costs will remain constant for the investment period.

The economic lifetime for bunker vessels is 20 years, tank trucks 10 years and 40 years for all other items. Therefore, the total time horizon of investment starting from 2015 is 40 years, i.e. after half that time bunker vessels/trucks are replaced with new ones. It is also assumed that the terminal operator owns and operates the entire infrastructure including bunker vessels and trucks.

4.1.2 Assumptions

For the purpose of this study and to be able to create a rational NPV mode, the required assumptions are summarized in a Table 4.2.

Table 4.2: Summary of Assumptions

Time Period			
Year of starting			2015
Asset life			40
Financial Estimations			
Salvage Value			14%
Discount Rate			15%
Euro/USD exchange rate			1.35
Calculation of cash flow as income			
Cost of LNG USD (Fixed for period)			590
Medium demand volumes revenue (million USD)			396.2
High demand volumes revenue (million USD)			594.4
Demand Scenarios		**Operating**	**Capital**
Capital cost of investment at medium demand	million €	4,7	104
	million USD	6,3	141
Capital cost of investment at high demand	million €	7,3	136
	million USD	9.9	184

4.1.3 Net Present Value Calculation

The results of the study were divided into two parts indicating a medium and high demand scenario and the calculations for each are shown in Appendix A. To assess if it would be financially feasible to develop an LNG bunkering infrastructure at the port of Cape Town and Durban, the NPV was determined using the formula in Figure 4.1.

$$NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i}$$

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

Figure 4.1: NPV Equation
(Source: http://www.financeformulas.net/Net_Present_Value.html.)

The NPV was calculated from the deduced capital and operating costs from Table 4.2 for both medium and high demand scenarios. If at the end of the economic life time of 40 years the NPV is positive, the investment would be considered economically feasible and if NPV is negative, the project can be rejected.

4.1.4 Results

NPV calculation shows a positive figure in both medium and high demand scenarios, and therefore it can be concluded that the development of LNG bunkering infrastructure is economically feasible at the port of Cape Town and Durban. However, the figures used herewith were based on a number of conservative assumptions in order to determine viability for the bunkering infrastructure project. It is expected that potential investors will conduct their own feasibility assessments using more accurate figures and consider unique conditions specific to each port.

4.2 SWOT Analysis

The SWOT analysis is a common methodology for analysing and reviewing a strategy, position, product or a business idea for a company. The letters is an acronym for Strength, Weakness, Opportunities and the Threat. A high level SWOT analysis was conducted for the purpose of this study in order to identify areas which may require further attention to enhance viability of LNG bunkering infrastructure development.

Table 4.3: SWOT Analysis

STRENGTHS	**WEAKNESSES**
• Higher supply completion leading to lower end-user prices • High supply diversity • Ability to optimise flows on a regional basis • Fossil free • Natural gas available in abundance	• Reliability of suppliers • Lack of infrastructure • Significant funding required for import terminals • Isolated planning between key stakeholders • Lack of skills and knowledge for handling LNG
OPPORTUNITIES	**THREATS**
• Government commitment to build CCGT power stations • Positive contribution to climate change • Unexplored market • Potential local supply from shale gas	• Public opposition due to safety concerns • Project rejection by environmental authorities • Unknown market • Competition from other fuels sources like MGO/HFO • Rules and regulations • No parallel bunkering and cargo handling

African region is emerging as a key supplier of natural gas, thereby increasing diversity of suppliers. Mozambique and Tanzania are showing great potential and both well positioned to supply the South African market given the distance which will result in lower prices for end-users and allow for SA to buy higher gas volumes.

The South African government is also committed to diversify energy sources and identified natural gas as a potential source. In effect, government has plans for the development of gas-fired power stations which require large volumes of gas to be imported for the investment to be viable. This presents an opportunity to set up an LNG bunkering infrastructure within identified ports. Furthermore, natural gas is a clean source of energy which will have a positive contribution towards climate change and it has a number of other environmental benefits outlined earlier in this study.

Table 4.3 also shows some weaknesses and threats facing LNG bunkering infrastructure development. Currently there is no LNG infrastructure in South Africa and this is constrained by significant investment costs required. Perceived safety concerns also present a major threat to the LNG developments and require attention to clear public concerns. In addition, current lack of skills and expertise for handling LNG may hamper the development. For instance, LNG bunkering vessel crew required the same level of competence as the crew of a large LNG tanker which has been accumulated over years. A DMA (2012) report suggests that this can be addressed by changing the criteria for training by customizing it to the smaller amounts that are handled on a bunker vessel.

Environmental issues have come to the forefront of construction developments in South Africa, especially in the marine environment. Therefore, there is a potential for project opposition from environmental groups and the public. The issue of perceived LNG safety risks will also be a concern which could result in public opposition or even projects being turned down by relevant authorities. It is, therefore, important to provide education and awareness for the authorities and the public and clear the perception by providing facts.

Overall, construction and operation of LNG bunkering infrastructure may potentially benefit the market and economy. The development is exposed to typical risks of any new market entrant and managing these risks early enough, it can help to mitigate the mentioned weaknesses.

4.3. Environmental Considerations

4.3.1 Environmental Assessment

The development of an intermediary terminal and other related infrastructures would require authorisation permits from relevant authorities. One of the key permit processes include Environmental Impact Assessment (EIA) as required by section 24 (1) of the National Environmental Management Act effected through the Environmental Impact Assessment Regulations, published in Government Notice R 543, 544, 545 and 546 on 18 June 2010 in Government Gazette 33306 (as amended) and enforced on 2 August 2010. As an example, some of the listed activities which may be triggered include but are not limited to those listed in Table 4.4.

Table 4.4: Environmental Impact Assessment listed activities

Government Notice R544 Activity No(s):	**Basic Assessment Activity**
11 (viii) and (xi)	The construction of: viii. jetties exceeding 50 square metres in size; xi. infrastructure or structures covering 50 square metres or more where such construction occurs within a watercourse or within 32 metres of a watercourse, measured from the edge of a watercourse, excluding where such construction will occur behind the development setback line.
3	The construction of facilities or infrastructure for the storage, or storage and handling of a dangerous good, where such storage occurs in containers with a combined capacity of more than 500 cubic metres.
Government Notice R545 Activity No(s):	**Description the relevant Scoping and EIA Activity**

6 (i) or (ii)	The construction of facilities or infrastructure for the bulk transportation of dangerous goods – (i) in gas form, outside an industrial complex, using pipelines, exceeding 1 000 metres in length, with a throughput capacity of more than 700 tons per day; (ii) in liquid form, outside an industrial complex, using pipelines, exceeding 1 000 metres in length, with a throughput capacity of more than 50 cubic metres per day;
26	Commencing of an activity, which requires an atmospheric emission licence in terms of Section 21 of National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004), except where such commencement requires basic assessment in terms of Notice of No. R544 of 2010.

In addition, the proposed project may result in the release of atmospheric emissions through its operations, thus requiring application for an Atmospheric Emission Licence (AEL) to be completed and submitted to the relevant AEL Authority. The requirement of an AEL Application arises from conducting a listed activity in terms of Section 21 of the National Environment Management: Air Quality Act (NEM: AQA) (Act 39 of 2004).

Public participation is a critical part of the EIA Process in South Africa and it assists in identifying issues and possible alternatives to be considered during the EIA Process. The objective of public participation is to ensure that people are afforded an opportunity to influence decision making from early on in the development. Literature shows that stakeholder reluctance to acceptance LNG projects is a major challenge due to the associated safety concerns. Evidently, between 2008 and 2009 PetroSA initiated an EIA process for the establishment of an LNG import facility in Mossel Bay. The project received intensive public opposition, and ultimately it was put on hold for other reasons and subsequently rejected by the Department of Environmental Affairs. This presents a significant risk to the development of LNG bunkering infrastructure and will require careful planning by TNPA and the industry.

International experience from existing LNG facilities show that early and good communication between the operator, authorities and the general public is essential for an efficient EIA process. Taking into account safety and environmental concerns throughout the project can help to ease the concerns of local authorities and communities. As both public, local and regional authorities as well as the media in general have little knowledge of LNG, it is vital to communicate the advantages of LNG as a fuel (DMA, 2012, p184).

4.3.2 Externalities of Ship Emissions

Emissions from vessels occur within the port area during manoeuvring, hotelling alongside or at anchor and during loading and unloading. As a result, these emissions are likely to have significant impact on local air quality and thus port emissions are an important consideration (Entec, 2007, p40). For the purpose of this study, the hotelling phase was further investigated specifically for a vessel at anchor and while the vessel is at berth in order to determine the potential impact on Durban or Cape Town communities around the port.

Emission estimates caused by burning fuel from the auxiliary engine (AE) during hotelling were established by using the Second IMO Greenhouse Gas study (2009) methodology as a guide. The following equation was used for the calculation of estimated emissions (Musyoka, 2013, p33):

Equation (1) $FC = P \times A \times LF \times SFOC \times EF$
$E = FC \times EC$

where E = emissions (grams[g])
FC = fuel consumption (tonnes [T])
P = power capacity (kilwatts [kW])
LF = load factor (percent of vessel’s total power)
A = activity (hours [h])
SFOC = specific fuel oil capacity (grams per kilwatts hour [g/kWh])
EF = emission factor (grams per kilowatt-hour [g/kWh])

Fuel consumption for the auxiliary engine was determined through the process illustrated in Figure 4.2 for each ship category. Input data for IMO emission inventory in Appedix B was used to provide data for AE power capacities, loading factors and SFOC. Average installed power (P) was established by multiplying the number of ships in each category with average AE power. The annual power outtake was then estimated by multiplying installed power with category specific estimate of the activity hours (A) of the auxiliary engine and the average load factor (LF). Finally, annual power outtake was multiplied with SFOC to get total fuel consumption.

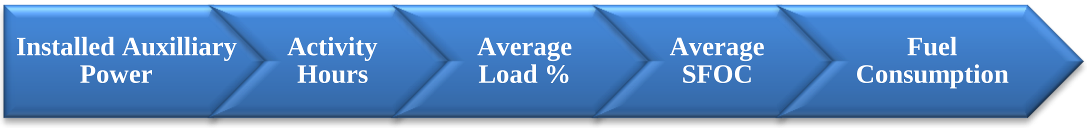


Figure 4.2: Calculation of fuel consumption (Source: IMO, 2009)

Emissions estimates were calculated by multiplying total fuel consumption with emission factors (EF). Several literature sources propose varying figures for emission factors; however, for the purpose of this study Entec revised emissions factors for year 2007 were used (Entec, 2010, p65). Externality costs were eventually calculated using data sourced from the EXIPOL (2011) study.

4.3.2.1 Estimated emissions for Durban/Cape Town

Emission figures for vessel traffic in Durban or Cape Town were determined based on ship calls for the 2013/14 TNPA financial year. The evaluation was only limited to selected ocean going vessels listed in Table 4.7 with the assumed number of vessels for each category. It was also assumed that each vessel will spend one day (24hrs) at anchorage waiting for berthing space and three days (72hrs) at berth loading and offloading cargo and this was used as total activity hours (96hrs) for each vessel.

Activity hours indicate the amount of time the auxiliary engine is used to provide power for the hotelling phase in each vessel. Therefore, the numbers of vessels for each category were multiplied by 96hrs in order to determine fuel consumption per annum. Tables 4.5 and 4.6 provide auxiliary engine data for the revised emission factors from Entec (2010) and SFOC from IMO GHG study (2009) respectively.

Table 4.5: AE Revised emission factors (g/kWh) (Source: Entec, 2010)

Engine	CO_2	NOx	SO_2	PM
Medium speed diesel	722	14.7	12.3	0.8

Table 4.6: SFOC (g/kWh]) (Source: IMO, 2009)

Engine age	**Above 800kW**	**Below 800kW**
Any	220	230

These figures were used in calculating the total fuel consumed as presented in Table 4.7 and thereafter emission estimates were established in Table 4.8. Since emission factors are provided in g/kWh, they were converted to get the value of each pollutant in tons. Likewise, total fuel consumption was also converted to tons in Table 4.7.

Table 4.7: Estimated Fuel Consumption

Vessel Cat	No of ships	Av. AE kW	Inst. Power kW	Activ. hrs	Load Factor	Annual Outtake kW.h	SFOC g/kWh	Fuel Consumed (Tonnes)
Container - 8000TEU+	500	3081	1540500	48000	60%	4.437E+10	230	10204272
General Cargo - 10000 dwt+	200	414	82800	19200	60%	953856000	220	209848.32
Oil Tankers 120000-199,999 dwt	50	1232	61600	4800	50%	147840000	230	34003.2
Vehicle 4000+ceu	50	1034	51700	4800	70%	173712000	230	39953.76

Table 4.8: Emission Estimates (Tonnes)

Vessel Categories	CO_2	NOx	SO_2	PM	Total
Container	7347.08	150	2.6	8.2	7507.9
General Cargo	151.1	3.09	2.59	1.68	158.46
Oil Tankers	24.5	0.5	0.42	0.27	25.69
Vehicle Carriers	28.8	0.58	0.49	0.32	30.19
Total	**7551**	**154.2**	**6.1**	**10.47**	**7722**

4.3.2.2 Environmental Gains

Literature review shows that the use of LNG as marine fuel will significantly reduce estimated ship exhaust emissions within and beyond the study areas. In particular, LNG has emission reduction potential which eliminates SOx emissions by 90%, NOx by 85%, PM by 90% and CO_2 by 20-25% less than other fuel sources (Jonsdottir, 2013).

To evaluate the environmental gain from ships using LNG in the port of Durban/Cape Town, emission reduction potential for each pollutant was used to determine the impact on the emission estimates established in this study. This was achieved by deducting the mentioned reduction potential from the total estimated emissions in Table 4.8 and the results were summarized in Table 4.9.

Table 4.9: Emission reduction

	CO_2	NOx	SOx	PM	Total
MGO	7551	154.2	6.1	10.47	7722
LNG	5663.25	23.93	0.61	1.047	5689
Total	1887.75	131.07	5.49	9.423	2034

Table 4.9 demonstrates that supplying LNG marine fuel to a number of vessels sampled in this study through the proposed bunkering infrastructure will significantly

reduce emissions of environmental pollutants and improve air quality around ports. Furthermore, it can be noted from graphical presentation of results in Figure 4.3 that of the four pollutants evaluated in this study, the greatest reduction will be achieved in SOx and PM emissions followed by NOx with CO_2 showing the lowest reduction in emissions. Total annual emissions from all vessels will be reduced from 7,722 tons to 5,689 tons, thereby resulting in environmental gain of 2,034 tons each year or 26%.

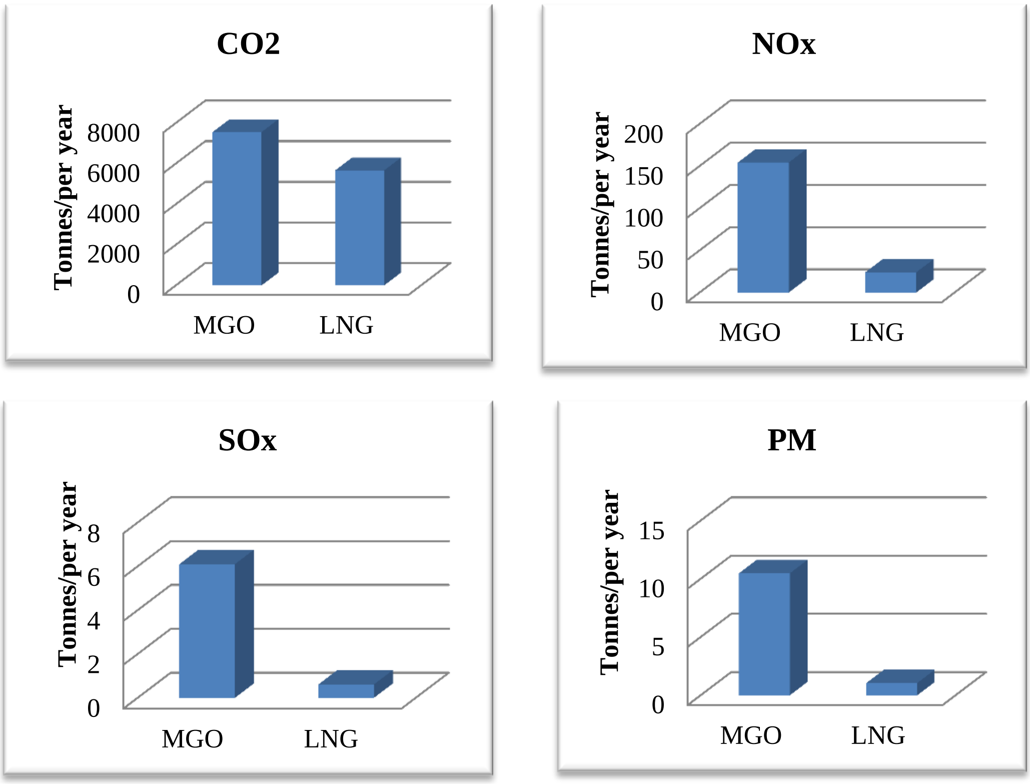


Figure 4.3: Emission reduction for Port of Durban/Cape Town

4.3.2.3 Cost of Externalities

There are many methods to estimate external costs of air pollution caused by ship emissions from studies conducted in other countries. However, it appears that no such study has been conducted in South Africa or anywhere in the region specifically for ship emissions. Therefore, in order to establish external costs for ship emissions within the scope of this study, the EXIPOL (2011) study was used to source required data. Although this is a European study, it was used for illustrative purposes to demonstrate the impact of ship emissions on different aspects in monetary value terms as reflected in Table 4.10. This table was adopted from a summary of EXIPOL findings developed by Peksen (2013) as it included EURO/USD conversions with key areas for health, ecosystem and climate change.

Table 4.10: External cost factors (in USD_{2012}) per ton for transport

Pollutant	Human Health	Ecosystem Quality	Climate Change	TOTAL
SO_2	7,738.84	245.68	0	7,984.52
NO_x	7,001.81	1,228.39	0	8,230.20
PM	429,935.80	0	0	429,935.80
CO_2	35.62	0	40.54	76.16

Based on the external cost factors in Table 4.10, total externality costs for ship emissions were calculated as presented in Table 4.11.

Table 4.11: Total cost of externalities

	Total Tonnes	EXIPOL	Externality cost (USD)
CO_2	7551	76.16	578406.6
NOx	154.2	8,230.20	1269096.84
SO_2	6.1	7,984.52	48705.6
PM	10.47	429,935.80	4501427.826
Total Externality Costs 2013/14			6397637

The outcome of the above analysis on selected vessel categories and the assumed number of vessels indicate the following:

- A total of 800 sample of different types and sizes of ships spending a day at anchor and 3 days in port for 2013/14 have discharged 7,722 tonnes of emissions (CO_2, NOx, SOx and PM) to the atmosphere, thereby exposing Durban or Cape Town communities to air pollution. Consequently, this has contributed to health care and medical expenses for human health impacts such as fatal diseases like bronchitis, asthma and lung cancer for the exposed communities. In addition, emissions have contributed to climate change and environmental damage around the port areas.
- The analysis also indicates that emissions from ships at anchor and in port for the 2013/2014 financial year has placed an estimated 6,397,637 USD extra financial burden on Durban/Cape Town economy, people and the environment.
- Figures used for a number of ships in ports and the selected vessel types and sizes were only based on a sample in the absence of data from TNPA. Therefore, it is expected that the total emissions will be significantly higher for all vessels operating in each port and thus the externality costs will also increase.

4.4 Safety

It has been widely reported that safety issues pose a significant business risk to LNG developments, largely due to safety concerns. This section seeks to provide a general overview of potential safety issues for the development of LNG bunkering infrastructure in South Africa, specifically in the port of Cape Town and Durban. A more comprehensive and specific safety risk assessment will still be required based on specific features and conditions prior to the development in each port. Moreover, the requirements for Occupational Health and Safety Act No.85 of 1993 and its Major Hazardous Installation (MHI) Regulations (2001) need to be considered.

4.4.1 Historical Experience

Historical accident data set out good basis to inform on the hazard identification process in order to address maritime safety issues (Richardson & Pearce, 2008). However, there is currently limited data available about LNG bunkering incidents as it is a new area with inadequate experience. Similarly, the port of Cape Town and Durban has no bunkering infrastructure and thus no risk profile for LNG bunker operations.

Nevertheless, literature shows that globally the LNG industry has excellent safety records from both the land and marine side with few incidents occurring over the past 60 years (Ditali & Fiore, 2008, p2; Koo, Soo Kim, Won So, Hwoi Kim & Yoon, 2009, p2). During the same period, no general public fatality has been caused LNG operations and the double hull designs of LNG tankers had a large impact on the confinement of vapours during accidents (Melhem, Kalelkar, Saraf & Ozog, 2006, p6; DMA, 2012b, p203). Melhem et al., (2006, p6) have attributed the good safety record to a number of factors including the use of multiple layers of safeguarding LNG tanks and transfer facilities, industry safety culture and exclusion zones to protect the public.

4.4.2 Safety Risk Assessment

There are number of risk assessment methodologies available, in particular TNPA has its own specific risk assessment methodology adopted and applied within the organisation. However, for the purpose of this study, a more generic approach was followed and focused on hazard identification, risk assessment and risk control measures. The risk assessment part was only limited to the review of potential causes and probabilities with attention to key bunkering activities and the risks were not quantified.

4.4.2.1 Hazard Identification (HAZID)

Hazard Identification (HAZID) is the process of systematically identifying hazards and associated events that have the potential to result in a significant consequence (to personnel, environment or any other third parties) (Kontova, 2005, p54). Potential hazards were identified from literature and highlighted within the context of risk assessment areas (Cape Town and Durban) for this study.

4.4.2.2 Risk Assessment Areas

Port of Cape Town

Cape Town is an established port in the Western region, providing container, bulk and general cargo handling services to the Western Cape and its largely agricultural hinterland. The port handles around 10 million tons of cargo per year (2 408 vessel calls), with the 30-year forecast predicting around 25 million tons of cargo per year. The port provides much-needed ship repair services in the Western Cape region, and hosts local and foreign fishing fleets, oil rigs, cruise liners and recreational users. The much older basins of the port were developed into the Victoria and Alfred Waterfront and now fall outside of port limits, complementing the commercial port by providing berthing for smaller recreation and fishing vessels. For the most part, the surrounding city land is zoned residential, with pockets of isolated industrial zones (Transnet, 2013, p158).

There are bunkering points at some berths, supplying fuel oil, gas oil and blended fuels. Bunkers are also supplied by barge. The Cape Town region enjoys a Mediterranean climate, but is also subject to the special factors of its southern latitude. During the winter months (April to September) north and northwest winds backing to the southwest are frequent. Westerly gales can cause heavy range action at berths; in the summer (October to March) the prevailing wind is from the southeast, which can reach gale force at times.
(http://www.transnetnationalportsauthority.net).

Figure 4.4: Port of Durban and Port of Cape Town
(Source: Transnet, 2013)

Port of Durban

Durban is South Africa's premier container port and is the principal port serving the KwaZulu-Natal province and the Gauteng region, as well as the Southern African hinterland. The port handles 3 991 vessel calls per year, which is the highest number in South Africa, equating to around 64 million tons of cargo per year. The 30-year forecast predicts around 175 million tons of cargo per year. Major growth areas for the port are seen to be in containers, bulk liquid handling and break bulk cargoes. The port is bounded by the city centre to the north, residential areas to the west and the east, and Transnet and other industrial land to the south (Transnet, 2013, p181).

The port of Durban has a dedicated berth for bunkering which is operated by Sapref under the Joint Bunkering Services system. Durban enjoys a sub-tropical climate with warm winters and temperatures ranging from 15°C-26°C. Summers are hot and humid with temperatures between 22°C and 35°C and periods of heavy rainfall. (http://www.transnetnationalportsauthority.net/).

4.4.2.3 Incident Analysis

When establishing the likelihood of an unwanted event occurring, it is important to take into consideration the historical record of incidents in the area (Richardson & Pearce, 2008, p29). In 2008, TNPA commissioned a risk assessment study for movement of dangerous goods in all the ports. The following marine incident summary (Table 4.12) was established for Cape Town and Durban for a period of 18.5 months and six years respectively.

Table 4.12: Marine incident summary

Incident Type	Cape Town	Durban
Vessel collisions	1	1
Contact berthing	1	9
Grounding	-	2
Fires (Vessel + pier)	1	11
Sinking	-	1
Contact damage	-	2
Vessel damage	-	1
Explosions	-	2
Gas leak	1	1
Vessel pollution	19	-

Although the above data is inadequate to make statistical conclusions and also not related to LNG, it was used as a risk profile to support the discussions presented herewith. The DMA analysis of global historical data suggests that many of the LNG incidents involved vapor release that was ignited leading to sometimes severe consequences (DMA, 2012b, p6). Therefore, this study will focus on identifying hazards related to vapor release during LNG bunkering activities.

4.4.2.4 Identification of Hazards

Hazard identification is a systematic process which requires input from different role players with a wide range of expertise on the subject. In this case, a number of literature sources were used to identify potential safety hazards related to LNG bunkering infrastructure (DMA, 2012; DNVGL, 2014, p38). To facilitate the discussion, identified hazards were grouped into different key operational categories (Table 4.13) as may be relevant to South Africa. These are hazards which were constantly rated high in literature and they were selected for the purpose of this study. There are several other hazards identified in literature which may be considered for a more comprehensive LNG risk assessment process (DMA, 2012, p173; DNV, 2013, p11).

Table 4.13: LNG hazards

Activity	Hazards
Loading/unloading of feeder vessel	• Overfilling risk because of difficulty to predict filling level in the receiving tank; • Failure of mooring adjustment during loading or tide variation
Feeder vessel transit	• Hard collision feeder/bunker vessel during transit from loading to unloading or bunkering; • Interaction with pleasure craft and bunker boat forced to manoeuvre during transit; • Blackout and grounding of bunker vessel;
Bunkering	• Leakage due to technical failure during bunkering from land-based facility; • Leakage from bunker connection and activation of ESD during ship-to-ship bunkering; • Mooring failure during bunkering alongside another ship and activation of ERS; • Pressure build-up due to liquid LNG left in vapour return lines after bunkering.

4.4.2.5 Impacts of LNG Hazards

There are number of potential outcomes and consequences following an accidental release of LNG and Figure 4.5 demonstrates some of the possible outcomes over water. The following overview highlights different categories of potential consequences (Parfomak & Vann, 2009, p4; Vanderbroek & Berghmans, 2012; Johnsdottie, 2013, p26; ABS, 2014, p10):

Cryogenic damage - Damage such as metal embrittlement, cracking and structural failure can be caused to the ship or infrastructure materials that cannot handle contact in cold temperatures.

Cryogenic Injuries - Serious injuries may occur to personnel in the immediate area or from the public if they come in contact with cryogenic liquids. Skin contact with LNG results in effects similar to thermal burns and with exposure to sensitive areas, such as eyes, tissue can be damaged on contact.

Asphyxiation - A large release of LNG close to people or a spill in enclosed non ventilated spaces could cause asphyxiation if there are large concentrations of natural gas in the air resulting in a deficiency of oxygen and if the air oxygen is replaced, methane asphyxiation may occur.

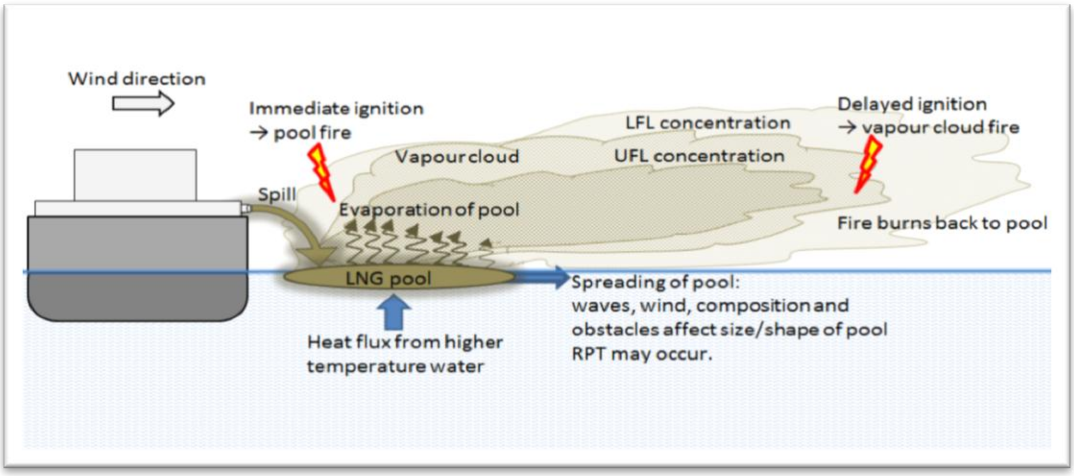


Figure 4.5: Possible outcome of LNG spill over water (Source: DMA, 2012)

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.

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). Since these LNG fires generate fairly low pressures, they are unlikely to cause pressure damages.

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 a high degree of confinement, a strong mixture with air and a large source of ignition, there is a potential for an explosion.

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 to an explosion, shock waves and over pressure can be formed. No combustion is involved.

4.4.2.6 Risk Analysis

The risk analysis process entails scoring the probability of occurrence and severity of consequence for each hazard (DNV, 2001, p37). The actual scoring of hazards was not conducted for this study as the process varies between different projects and requires a multidisciplinary team. However, the discussion focuses on causes and probabilities of hazards identified from literature where the ALARP (As Low As Reasonably Practicable) principle was applied (Figure 4.6).

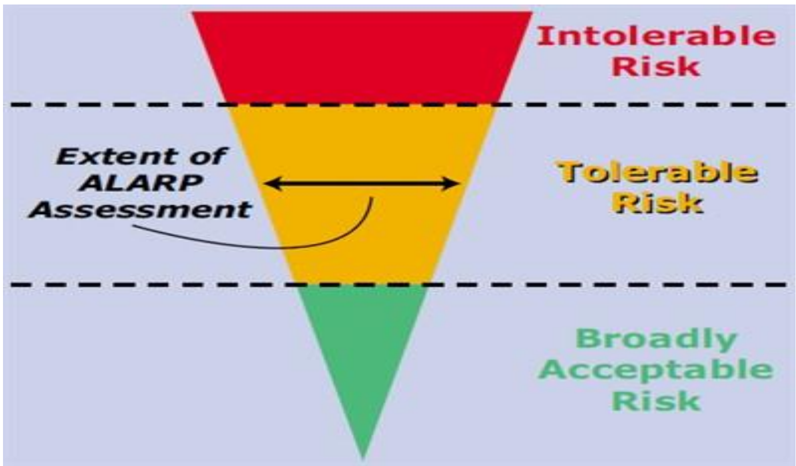


Figure 4.6: ALARP range (Source: http://www.risktec.co.uk/)

Factors Contributing to Identified Hazards

The following discussion provides an overview of contributing causes and probabilities of identified hazards in relation to each key activity. Due to the generic nature of this section, identified causes are non-specific and seek to guide individual assessments required for both the port of Cape Town and Durban. Table 4.14 provides a list of potential accident scenarios with source of release and possible causes.

a) LNG Release During Loading/Unloading

Although bunker activities involve smaller volumes compared to import terminals, they also present a significant risk with specific potential accident causes identified in Table 4.14 (Richardson & Pearce, 2008, p32; DMA, 2012, p173).

It can be noted from potential accident scenarios and causes that siting and layout of LNG terminals require risk based planning including navigational safety assessment and special consideration paid to the siting with regard to potential cascading domino effects. Both the port of Cape Town and Durban face a challenge in this respect given the various activities already established in the ports and close proximity of the residential areas. Therefore, siting will be critical to determine viability of LNG bunkering infrastructure developments in both ports.

Table 4.14: LNG accident scenarios and causes (Source: DNVGL, 2014)

Source of release	Scenario	Possible causes
General process and cargo handling	Accidental release from equipment and cargo handling	Lack of flange tightness
		Defective gasket
		Weld defects
		Corrosion
		Supporting structure damage
		External fire
		Overpressure (e.g pressure test during commission)
		Embrittlement
		Earthquake, floods, and other natural hazards
Accidental release from LNG tanks at jetty or on ships	Ship collision	Passing ship adrift
	Ship pressure relief valve	Overpressure
		Rollover
Onshore storage	Tank leakage	Dropped in tank pump
		Internal or external leak in tank bottom or wall
		Earthquake
		Catastrophic rupture and leakages

	Tank Pressure Safety Valve (PSV) release	Tank overfilling
		Tank overpressure
		Rollover
	BLEVE (Boiling liquid expanding vapour explosion)	Fire impact on pressurised hydrocarbon liquid container. BLEVE is only considered as a potential threat for pressurised storage tank, where the loading structure is exposed to fire loads.
Loading/unloading lines	Leaks from piping and manifold	See general
Accidental release from loading arm or hose	Leak/full bore rupture	Mechanical failure mode
		Loss of mooring, drift off
		Passing ship adrift
		Ship collision
LNG truck	Release during transfer	Rupture of transfer hoses, truck or piping. Operational errors, mechanical errors
		Catastrophic rupture, warm BLEVE
LNG supply ship	Leakage from cargo tank	Structural damage
		Collision damage if this is identified as a credible risk in the HAZID

b) LNG Release during Transit in the Port Area

Typical accident types during transit include collision, grounding, bridge/quay collision, engine room fire, blackout, rudder failure, etc (DNVGL, 2014, p38). This may be attributed to different causes like human error, technical failure, external causes from extreme weather or interacting traffic or causes related to deficiencies in managerial systems (Richardson & Pearce, 2008, p32; DMA, 2012, p173):

Incident analysis shows that the port of Durban had collision, grounding, sinking and contact incidents while Cape Town had collision and contact incidents within the sample period. In addition, Cape Town and Durban have higher vessel traffic compared to other South African ports including a lot of recreational vessels. Moreover, the port of Cape Town is susceptible to gale force winds and other weather challenges which may affect LNG operations. An IMDG report made reference to an explosion incident at Island View in Durban, where the public impact was minimised due to wind direction. Thus, given the risk of an LNG vapour cloud, prevailing wind conditions will be critical for LNG operations within both ports.

c) LNG Release during the Bunkering Operation

Firstly, LNG release during bunkering operation is largely caused by technical and human factors, including external causes. This includes leaking flanges, broken hose connections, and excessive relative motions between the ships (DNVGL, 2014, p38) are examples of events that will activate the ESD systems but are also events that may lead to the release of LNG on the vessels or into the water (DMA, 2012, p173).

The greatest challenge that SA port will face during bunkering operations is lack of skills and expertise for LNG activities and this could significantly compromise safety. In addition, STS/TTS of LNG fuelled vessels berthed at quays close to residential areas may create problems in both ports. This also raises safety issues regarding LNG truck movement through the city and high traffic areas around the port. Challenges related to traffic congestion to the port were also identified as a concern during the TNPA IMDG risk assessment study.

4.4.2.7 Risk Control Measures

Prevention of LNG incidents is the main priority to maintain the current good safety record within the industry. However, control measures must be established to ensure effective response to minimise the impact in the event that an incident occurs. The following discussion provides an overview of potential risk control measures that should be considered in the development and operation of LNG bunker facilities in

South Africa. Control measures should be based on LNG related international regulations, codes, and standards.

a) Safety Management System (SMS)

SMS should be developed and implemented as a cornerstone for overall LNG bunkering risk control measures. ISO118683 draft guidelines also require bunkering operations to be conducted under the control of a recognised safety management system. The system should be applicable to all parties involved in the design, construction and commissioning or execution of bunkering operations (DNVGL, 2014, p23).

Communication is the key success to effective SMS to ensure adequate communication between all the role players and most importantly the interface between feeder/bunker vessel crew and onshore team. This should also include measures for ship compatibility which should be confirmed through communication.

Standard Operating Procedures (SOPs): should be developed in line with international best practices and standards like ISO 28460:2010, as modified for smaller terminals and ports (DMA, 2012). Although LNG will be new to Cape Town and Durban – TNPA IMDG SOP already made provisions for handling LNG import vessels within the port and this will need to be reviewed to allow for smaller feeder/bunker vessels. In addition, the port authority should consider developing LNG bunkering guidelines with the industry to ensure consistency and a set of minimum requirements for compliance. The guidelines should also make provision for LNG carriage by road in line with international standards.

Design requirements: Literature review shows that LNG containment systems have contributed significantly in minimising impacts during accidental release. Therefore, connections and the integrity of tank containment both onshore and on-board vessels must be maintained together with other equipment and systems, automatic shutdown in case of power outage or overload etc. (DMA, 2012).

Monitoring: Also key to the implementation of the system is focus on critical elements such as deviation control; therefore, surveillance, detection, preparedness, emergency practices together with routines for pressure control and spill surveillance must be in place (DMA, 2012).

Training: As mentioned earlier, SA does not have the required skills and expertise for LNG operations due to current lack of infrastructure. The human element can lead to catastrophic consequences if not managed accordingly and thus all role players involved in LNG operations should be competent to work with flammable gases. Education and training especially for onshore personnel should be prioritised to build adequate capacity to operate LNG bunkering facilities, monitoring and compliance enforcement for oversight authorities. Also critical to the safety system is the training and education of personnel involved in the operation (IFC, 2007, p3).

b) Emergency Preparedness and Response

The possibility of an emergency situation should be considered through the SMS (DNVGL, 2014, p27) to ensure development of effective emergency plans for the terminal and vessels in line with the international standards (SIGTTO etc.). More importantly, terminal and vessel emergency plans should complement each other to avoid confusion and conflict (IFC, 2007, p3).

Emergency response measures are already in place at the port of Cape Town and Durban. However, a gap analysis should be conducted to determine what additional resources will be required to ensure there are adequate and specific measures for LNG operations. The requirements of ISO 28460:2010 standard must be considered with regard to fire fighting and the availability of a standby tug for small scale operations.

c) Marine Control Measures

Vessel Traffic Services (VTS) is critical to prevention of vessel collisions, groundings and other vessel incidents within the port (Richardson & Pearce, 2008). South African commercial ports have a well established VTS system that has been running for years. However, if LNG bunkering infrastructure is developed, VTS personnel will need to be educated and trained accordingly to manage LNG vessels within the port.

A Pilot Exemption Certificate (PEC): Risk assessment should be conducted for the option to issue PEC to LNG feeder/bunker vessels master with consideration to unique conditions in each port. The requirement of using tugs for feeder and bunker vessel movement should be also be considered and assessed (Richardson & Pearce, 2008, p55).

Dedicated LNG carrier anchorage: South African ports have designated areas for anchorage of all vessels waiting for berthing space in the port. In line with the ISO 28460 standard, dedicated LNG vessel anchorage areas need to be identified to minimise the risk of collision and these should be enforced through the VTS centre once designated.

Weather: It was noted that the port of Cape Town is susceptible to gale force winds and therefore weather operating restrictions should be established. Such restrictions may include current, wind loads, tidal range; light conditions and visibility, waves and swell (Richardson & Pearce, 2008, p55).

d) Separation of LNG Bunkering and Safety Distances

The main objective of safety distance is to mitigate the effect of a credible incident and prevent a minor incident from escalating into a larger incident. Siting and safety distance requirements applicable to a large terminal will also be applicable to intermediary terminals (DMA, 2012). This will pose a challenge for TNPA and will require careful planning in view of limited open spaces available within target bunkering ports to allow for the required safety distances.

As noted in the incident analysis, the risk of collisions or grounding exists at the port of Cape Town and Durban. Therefore, for a bunker/feeder vessel in transit, TNPA should consider regulating bunker vessel traffic and port access and establishment of clearance zones. The ports also have road traffic congestion problems which could potentially constrain the use of LNG tank trucks, and this will require further investigation.

There are well established processes used to guide safety distances for large-scale LNG spills over water and the same may also be applied for LNG bunkering and potential release of LNG (DNVGL, 2014, p42). Therefore, TNPA must establish a process for determining safety zones with consideration to different bunker methods, scale, the vessels and the surrounding. In addition, the authority will need to interrogate and assess the possibility to allow parallel passenger/cargo handling and bunkering operations. It is also noteworthy to mention that viability of LNG as marine fuel may depend on a decision to allow parallel operations in order to compete with other fuel sources.

CHAPTER 5 - SUMMARY AND CONCLUSION

South Africa is geographically well positioned along one of the main global shipping routes the Cape of Good Hope. The study indicates that the country has potential to take the opportunity of its position through the supply of LNG as marine fuel. LNG marine fuel demand outlook shows positive prospects boosted by the abundance of natural gas throughout the world. A number of key drivers for LNG as marine fuel have been outlined in the study from a regulatory, environmental and economical perspectives. However, it appears that LNG availability as marine fuel and price are the main constraints and they are largely based on the development of an LNG supply chain infrastructure. This is because an LNG bunkering infrastructure is capital intensive and sensitive to LNG price and the volumes required for the project to be viable.

A number of scenarios for the development of LNG import terminals have been put forward between Transnet and the Western Cape government in South Africa. The business case for each scenario has its own merits to justify the investment without reliance on LNG demand as marine fuel from the shipping industry. These present an excellent opportunity for South Africa to build an LNG marine fuel supply chain from the proposed developments. The study has, therefore, proposed the downstream supply chain and the development of an LNG bunkering infrastructure with attention to the port of Cape Town and Durban as the preferred bunker ports for all development scenarios. The scenario for development of the Western Cape LNG import terminal, however, presents several challenges for the establishment of a bunkering infrastructure and may significantly increase the cost of LNG marine fuel supply and result in loss of demand.

Financial evaluation for the proposed bunkering infrastructure shows positive results at both estimated medium and high demand indicating that the development is economically viable. Land based demand outlined in the study provides an opportunity to supplement demand from the intermediary LNG facility and this will allow benefits from economies of scale and high utilization and thus enable a terminal operator to charge lower LNG marine fuel prices to stimulate demand.

With regard to environmental issues, LNG as marine fuel offers significant environmental benefits as outlined in the study. In terms of the EIA requirements, the development of an intermediary tank infrastructure will trigger the need for environmental assessment and no environmental flaws were identified for both Cape Town and Durban. However, this will depend on the location of the terminal in relation to sensitive environmental attributes of each port. Moreover, the analysis of ship emission externalities shows that total annual emissions from selected vessels will be reduced from 7722 tons to 5689 tons, thereby resulting in environmental gain of 2034 tons each year or 26%. Additionally, evaluation of externality costs indicates that emissions from ships at anchor and in port for the 2013/2014 financial year has placed an estimated 6,397,637 USD extra financial burden on Durban/Cape Town economy, people and the environment. Figures used for a number of ships in ports and the selected vessel types and sizes were only based on a sample in the absence of data from TNPA. Therefore, it is expected that the total emissions will be significantly higher for all vessels operating in each port and thus the externality costs will also increase. On the other hand, emission reduction potential of LNG compared to other fuel sources positions it as an attractive energy source to reduce externality costs.

From a safety perspective, it has been noted that safety issues present a potential fatal flaw for the development of a bunkering infrastructure if they are not managed carefully. Despite an excellent safety record for the industry, there are still fears from the public and other relevant stakeholders that LNG poses an unacceptable risk. While the hazards associated with handling of LNG clearly have potential for severe consequences, the LNG industry has equally responded by introducing a number of risk control measures. Some of the key measures include multiple layers of safeguarding LNG tanks and transfer facilities which have proven to be effective and siting of LNG facilities and safety zones to avoid impact on the public. In the context of LNG bunkering supply chain in South Africa, existing control measures pose a challenge with regard to ensuring a balance with other port activities. Chiefly, the required decision to allow LNG bunkering in parallel to other port activities is critical for LNG to be competitive with other fuel sources.

Furthermore, one of the greatest challenges that SA ports will face for bunkering operations is lack of skills and expertise for LNG activities and this could significantly compromise safety. The close proximity of the port of Cape Town and Durban to residential and other populated areas present another key challenge in as far as siting of the terminal is concerned. This also raises safety issues regarding LNG truck movement through the city and high traffic areas around the port. Nonetheless, other international ports have successfully introduced risk control measures to address similar challenges and this can be investigated further to determine suitability and adoption in South Africa. Moreover, there are existing international industry standards and guidelines for bulk LNG handling and these can be customised for bunkering operations to ensure that the level of risk is acceptable.

In view of the above, it can, therefore, be concluded that the development of an LNG bunkering infrastructure in South Africa is viable. However, safety issues present a significant risk which could hamper the development and require further attention to allay fears from the public and relevant stakeholders. Moreover, there appears to be fragmented planning between Transnet and Western Cape and this should be addressed accordingly to ensure holistic planning for optimised utilisation of state resources. The results of this study might lead to future projects or studies of similar subjects about LNG bunkering infrastructure for the other South African ports or similar small scale facilities.

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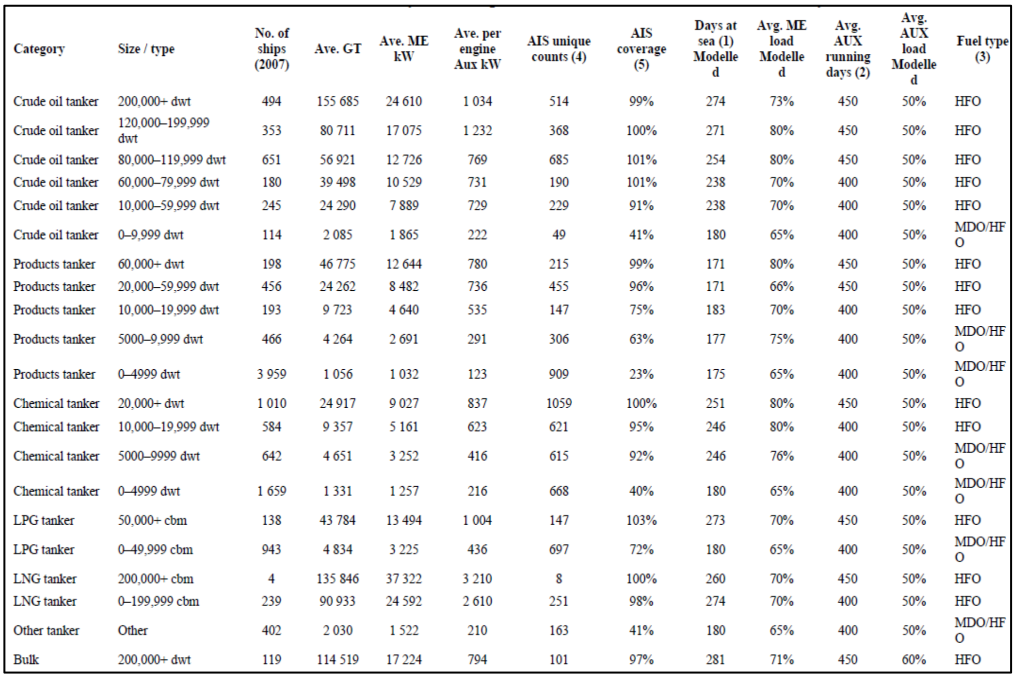
APPENDIX A

Financial Evaluation @ Medium 20%										
	0	2015	2020	2025	2030	2035	2040	2045	2050	2055
	$m	$m	$m	$m	$m	$m	$m	$m	$m	$m
Total Investment Costs	141									
Total Benefits and Revenue		396.2	396.2	396.2	396.2	396.2	396.2	396.2	396.2	396.2
Total Operating and Maintenance Costs		6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Salvage										14
Net Income	141	389.9	389.9	389.9	389.9	389.9	389.9	389.9	389.9	389.9
Business Case Results:										
Present Value	2589.7									
Net Present Value	2448.7									

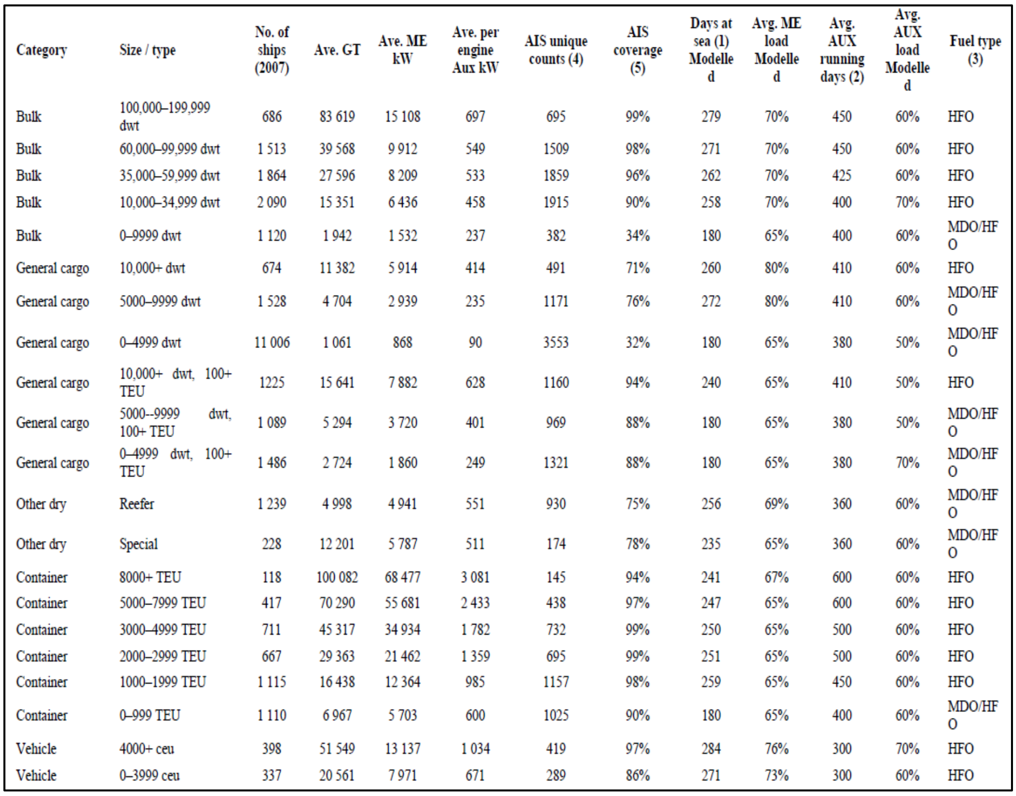
Financial Evaluation @ Medium 30%										
	0	2015	2020	2025	2030	2035	2040	2045	2050	2055
	$m	$m	$m	$m	$m	$m	$m	$m	$m	$m
Total Investment Costs	184									
Total Benefits and Revenue		594.4	594.4	594.4	594.4	594.4	594.4	594.4	594.4	594.4
Total Operating and Maintenance Costs		9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
Salvage										14
Net Income	184	584.5	584.5	584.5	584.5	584.5	584.5	584.5	584.5	584.5
Business Case Results:										
Present Value	3882.2									
Net Present Value	3698.2									

APPENDIX B

Input Data for IMO emission inventory (Source: IMO, 2009)



Category	Size / type	No. of ships (2007)	Ave. GT	Ave. ME kW	Ave. per engine Aux kW	AIS unique counts (4)	AIS coverage (5)	Days at sea (1) Modelled	Avg. ME load Modelled	Avg. AUX running days (2)	Avg. AUX load Modelled	Fuel type (3)
Crude oil tanker	200,000+ dwt	494	155 685	24 610	1 034	514	99%	274	73%	450	50%	HFO
Crude oil tanker	120,000–199,999 dwt	353	80 711	17 075	1 232	368	100%	271	80%	450	50%	HFO
Crude oil tanker	80,000–119,999 dwt	651	56 921	12 726	769	685	101%	254	80%	450	50%	HFO
Crude oil tanker	60,000–79,999 dwt	180	39 498	10 529	731	190	101%	238	70%	400	50%	HFO
Crude oil tanker	10,000–59,999 dwt	245	24 290	7 889	729	229	91%	238	70%	400	50%	HFO
Crude oil tanker	0–9,999 dwt	114	2 085	1 865	222	49	41%	180	65%	400	50%	MDO/HFO
Products tanker	60,000+ dwt	198	46 775	12 644	780	215	99%	171	80%	450	50%	HFO
Products tanker	20,000–59,999 dwt	456	24 262	8 482	736	455	96%	171	66%	450	50%	HFO
Products tanker	10,000–19,999 dwt	193	9 723	4 640	535	147	75%	183	70%	400	50%	HFO
Products tanker	5000–9,999 dwt	466	4 264	2 691	291	306	63%	177	75%	400	50%	MDO/HFO
Products tanker	0–4999 dwt	3 959	1 056	1 032	123	909	23%	175	65%	400	50%	MDO/HFO
Chemical tanker	20,000+ dwt	1 010	24 917	9 027	837	1059	100%	251	80%	450	50%	HFO
Chemical tanker	10,000–19,999 dwt	584	9 357	5 161	623	621	95%	246	80%	400	50%	HFO
Chemical tanker	5000–9999 dwt	642	4 651	3 252	416	615	92%	246	76%	400	50%	MDO/HFO
Chemical tanker	0–4999 dwt	1 659	1 331	1 257	216	668	40%	180	65%	400	50%	MDO/HFO
LPG tanker	50,000+ cbm	138	43 784	13 494	1 004	147	103%	273	70%	450	50%	HFO
LPG tanker	0–49,999 cbm	943	4 834	3 225	436	697	72%	180	65%	400	50%	MDO/HFO
LNG tanker	200,000+ cbm	4	135 846	37 322	3 210	8	100%	260	70%	450	50%	HFO
LNG tanker	0–199,999 cbm	239	90 933	24 592	2 610	251	98%	274	70%	400	50%	HFO
Other tanker	Other	402	2 030	1 522	210	163	41%	180	65%	400	50%	MDO/HFO
Bulk	200,000+ dwt	119	114 519	17 224	794	101	97%	281	71%	450	60%	HFO



Category	Size / type	No. of ships (2007)	Ave. GT	Ave. ME kW	Ave. per engine Aux kW	AIS unique counts (4)	AIS coverage (5)	Days at sea (1) Modelled	Avg. ME load Modelled	Avg. AUX running days (2)	Avg. AUX load Modelled	Fuel type (3)
Bulk	100,000–199,999 dwt	686	83 619	15 108	697	695	99%	279	70%	450	60%	HFO
Bulk	60,000–99,999 dwt	1 513	39 568	9 912	549	1509	98%	271	70%	450	60%	HFO
Bulk	35,000–59,999 dwt	1 864	27 596	8 209	533	1859	96%	262	70%	425	60%	HFO
Bulk	10,000–34,999 dwt	2 090	15 351	6 436	458	1915	90%	258	70%	400	70%	HFO
Bulk	0–9999 dwt	1 120	1 942	1 532	237	382	34%	180	65%	400	60%	MDO/HFO
General cargo	10,000+ dwt	674	11 382	5 914	414	491	71%	260	80%	410	60%	HFO
General cargo	5000–9999 dwt	1 528	4 704	2 939	235	1171	76%	272	80%	410	60%	MDO/HFO
General cargo	0–4999 dwt	11 006	1 061	868	90	3553	32%	180	65%	380	50%	MDO/HFO
General cargo	10,000+ dwt, 100+ TEU	1225	15 641	7 882	628	1160	94%	240	65%	410	50%	HFO
General cargo	5000--9999 dwt, 100+ TEU	1 089	5 294	3 720	401	969	88%	180	65%	380	50%	MDO/HFO
General cargo	0–4999 dwt, 100+ TEU	1 486	2 724	1 860	249	1321	88%	180	65%	380	70%	MDO/HFO
Other dry	Reefer	1 239	4 998	4 941	551	930	75%	256	69%	360	60%	MDO/HFO
Other dry	Special	228	12 201	5 787	511	174	78%	235	65%	360	60%	MDO/HFO
Container	8000+ TEU	118	100 082	68 477	3 081	145	94%	241	67%	600	60%	HFO
Container	5000–7999 TEU	417	70 290	55 681	2 433	438	97%	247	65%	600	60%	HFO
Container	3000–4999 TEU	711	45 317	34 934	1 782	732	99%	250	65%	500	60%	HFO
Container	2000–2999 TEU	667	29 363	21 462	1 359	695	99%	251	65%	500	60%	HFO
Container	1000–1999 TEU	1 115	16 438	12 364	985	1157	98%	259	65%	450	60%	HFO
Container	0–999 TEU	1 110	6 967	5 703	600	1025	90%	180	65%	400	60%	MDO/HFO
Vehicle	4000+ ceu	398	51 549	13 137	1 034	419	97%	284	76%	300	70%	HFO
Vehicle	0–3999 ceu	337	20 561	7 971	671	289	86%	271	73%	300	60%	HFO