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STUDIES ON THE FEASIBILITY AND USE OF LNG AS A FUEL FOR SHIPPING

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Studies on the feasibility and use of LNG as a fuel for shipping

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Feasibility study on the use of LNG as a fuel for international shipping in the North America ECA

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List of abbreviations and acronyms

CNG	Compressed Natural Gas
dwt	Dead Weight Tonnage (total weight of a ship's cargo, fuel, etc.)
ECA	Emission Control Area
ESD	Emergency Shut Down
FOB	Free On Board (with regard to bunker prices)
FOC	Fuel Oil Consumption
FSPO	Floating Storage, Production and Offloading
GT	Gross Tonnage (an index of ship's overall internal volume)
HFO	Heavy Fuel Oil
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF	International Code of Safety for Ships using Gases or other Low Flashpoint Fuels (IGF Code)
IMO	International Maritime Organization (www.imo.org)
ISO	International Organization for Standardization
LFL	Lower Flammability Level
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MMBtu	Million British Thermal Unit, 1 MMBtu = 293 kWh = 1.055 MJ
OSV	Offshore Supply Vessel (often used in the US instead of PSV)
PSV	Platform Supply Vessel
SIGTTO	Society of International Gas Tanker and Terminal Operators
TPS	Bunkering from storage Tank via Pipeline to Ship
STS	Ship To Ship (LNG bunkering concept)
TTS	Truck To Ship (LNG bunkering concept)
UFL	Upper Flammability Level
WSF	Washington State Ferries
MARPOL	International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto.

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1 Introduction

DNV GL was engaged by the International Maritime Organization (IMO) to study the feasibility of using LNG (Liquefied Natural Gas) as a ship fuel for international shipping in the North American Emission Control Area (ECA). IMO is in the process of identifying the feasibility for LNG as a fuel for shipping in the North American ECA that came into effect on 1 August 2012.

The objective of this study was to gather new knowledge about the potential of LNG powered shipping in the North American ECA and identify the necessary conditions for the successful implementation of LNG as a fuel source for shipping in the region.

1.1 Background

IMO is a specialized agency of the United Nations. It has responsibility for the regulation of international shipping, in particular for the safety of life at sea and the prevention of marine pollution.

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of operational or accidental pollution of the marine environment by ships. MARPOL Annex VI, specifically addressing air pollution from ships, entered into force in 2005.

A significant challenge for shipping is that it is required under MARPOL Annex VI to meet increasingly stringent emission limits for pollutants within Emission Control Areas (ECAs).

These are regions where local ecological, oceanographical or vessel traffic patterns justify a higher level of protection from pollution. Figure 1 summarizes the changes to the global and ECA sulphur limits over time.

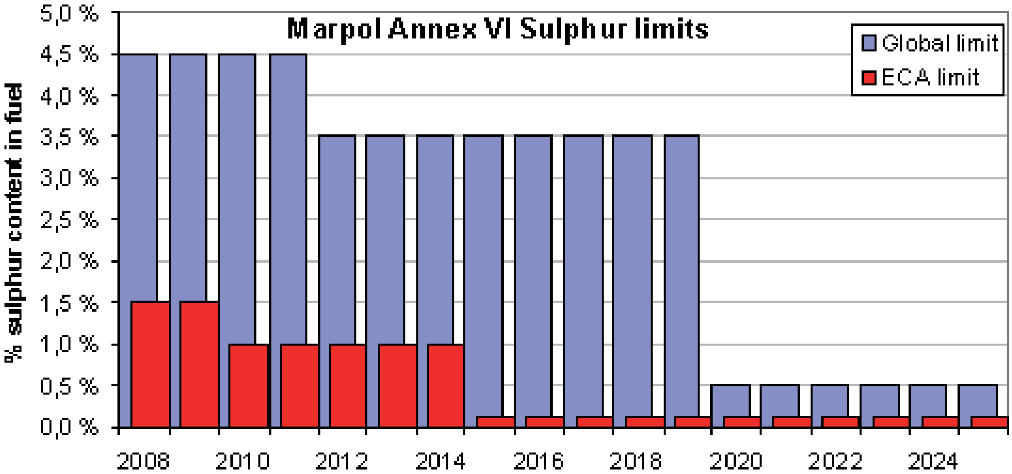


Figure 1: *Worldwide and ECA sulphur limits on marine diesel fuels*

As can be seen, 2015 will be a significant milestone for the reduction of sulphur inside ECAs, as well as 2020 when the global limit on the emission of sulphur oxides (SO_x) will see a significant reduction. In addition, 2016 will see the Tier III nitrous oxide (NO_x) requirement for new build vessels come into force. Looming on the horizon is also the real possibility of the establishment of more ECAs around the world. A further challenge to the regulatory environment is the increasing cost of fuel and the expected increase in the cost of low sulphur fuel when the demand sharply rises.

The three main options currently available to the industry to meet air quality environmental targets are: using low sulphur fuels/distillates, installing exhaust gas cleaning systems or using liquefied natural gas (LNG) as a primary fuel.

Ships carrying LNG as cargo have been fuelled by gas for over 50 years. The first merchant ship which was not an LNG carrier and which used LNG as a fuel source was the Norwegian ferry **GLUTRA** which was built in 2000. DNV issued the first Classification Society Rules in 2001 for gas fuelled ships and these rules were used as input for the IMO Interim Guidelines on Safety for Natural Gas-fuelled Engines, resolution MSC 285(86).

Since 2001, over 40 LNG fuelled merchant ships have been built and are operating with about a further 40 ships under construction or undertaking conversion (as of October 2013). Of the confirmed new builds and conversions about 15 are in North America.

However, despite the increasing interest driven primarily by the need to comply with ECA regulations there is still significant work to be done to determine the full potential and extent to which LNG, as a potential fuel source, is a truly viable option for wider application.

Currently, there are three MARPOL Annex VI designated ECAs worldwide: the Baltic Sea Area, the North Sea Area and the North American ECA. In addition, a US Caribbean Sea Emission Control Area will enter into effect on 1 January 2014. As the health and environmental benefits of reducing airborne pollution are increasingly quantified it is possible that other regions may apply for an ECA designation in the future.

The use of LNG is considered to have significant environmental advantages. An LNG fuelled ship reduces the emissions of NO_x by 85% to 90% (using a gas only engine), and SO_x and particles by close to 100% compared to today's conventional fuel oil. In addition, LNG fuelled ships may result in a net reduction of greenhouse gas (GHG) emissions.

There is significant variation in the LNG price among various geographic regions. Due to shale gas availability, North America has the lowest natural gas price, with natural gas (Henry Hub price) trading in a range from 2 to 4 USD/mmbtu since 2012. However, the actual price of LNG delivered to a ship's fuel tanks is a critical factor in the financial feasibility analysis and this cost is subject to some uncertainty based on the supply chain as well as the pricing model chosen by the supplier.

Shipping plays a vital role in the movement of goods within the North American ECA, with many remote communities heavily reliant upon it for commodities. Further there is a need to consider increased operation of cruise passenger ships within the North American ECA. Policy makers and regional governments, realizing the importance of a clean and healthy environment to their people as well as to their economies, are looking for sustainable, cleaner alternatives.

The most critical issue is adequate fuelling (bunkering stations) facilities; how to provide sufficient supply of fuel to ships safely, efficiently and reliably. Shipboard design is also important, and the primary question in this regard is: could existing vessels in the region be retrofitted or will new builds be required.

1.2 Geographic coverage

The area of the North American ECA includes waters adjacent to the Pacific coast, the Atlantic/Gulf coast and the eight main Hawaiian Islands. It extends up to 200 nautical miles from coasts of the United States, Canada and the French territories, except that it does not extend into marine areas subject to the sovereignty or jurisdiction of other States. It also includes the St Lawrence Seaway, the Great Lakes and rivers (such as the Mississippi), which are accessed by international shipping. Figure 2 shows the North American Emission Control Area that came into effect on 1 August 2012.

Figure 2: *North American Emission Control Area [EPA 2010]*

2

International shipping in NA ECA

The shipping in the North American ECA consists of domestic shipping in the US and Canada, shipping between the two countries, and other international trade and vessels calling at ports in the US and Canada. Though the scope of this study is the feasibility of using LNG as a fuel source for international shipping, it is also important to discuss the domestic shipping in North America as this is a key driver in the demand for LNG as a shipping fuel, the infrastructure development, and for the implementation of domestic regulations and requirements.

Therefore, in the following chapter, the shipping segments and trade patterns are examined for international shipping in the NA ECA, as well as the domestic activity for US and Canadian shipping.

2.1 Major shipping routes and trade patterns

In Figure 3 the major shipping routes worldwide are shown.[1] The data was compiled from 1,469 ports and comprises nearly 3 million ship journeys, from 32,000 ships of any type and any size above 10,000 GT during 2007 to 2008. It is clearly seen that some of busiest shipping routes are into and within the North American ECA.

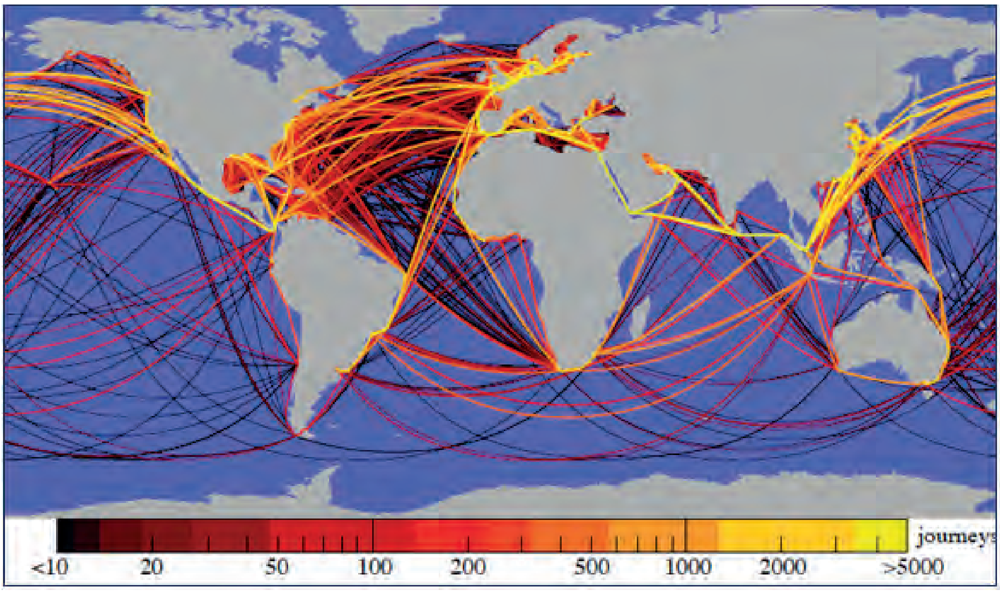


Figure 3: *Major shipping routes*

Especially, the cargo ship traffic intensity in the Eastern seaboard and the Gulf of Mexico is very high.

2.2 Shipping overview and trade statistics

In order to get an overview of the shipping traffic in the ECA, statistical data collected from various databases and agencies can be used. In this study, the focus was to identify the ports with the most vessel calls, the busiest port and the type of vessel. Appendix B lists the total cargo volume for the US and Canadian ports, including domestic and international trade.

A closer look of the trade pattern in the ECA is carried out based on an analysis of vessel calls in all the major ports in USA. The data is collected from the US Army Core of Engineers[2] and covers all domestic and international vessel calls in 2011. The analysis of the data is presented in Appendix B, some of the main results are presented in the following figures.

Figure 4 shows all the vessel calls listed by ship type for the 20 busiest ports in US, both domestic and international calls.

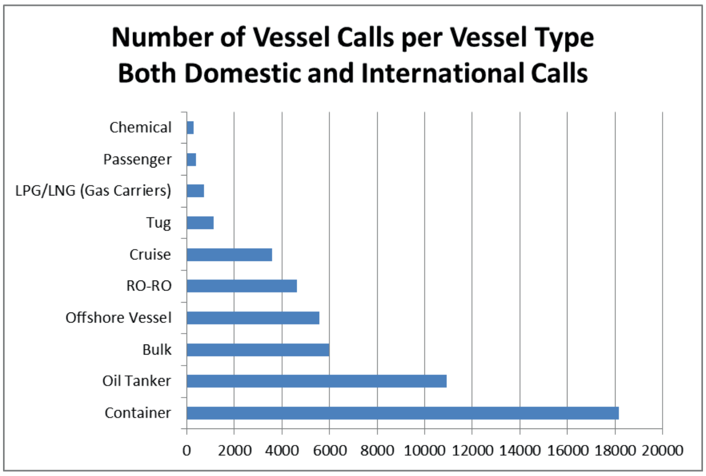


Figure 4: *Vessel call by ship type*

The next figure shows the 20 busiest ports in the US ranked by the number of vessel calls. A vessel call used in the following tables and graphs is based on the port entry data.

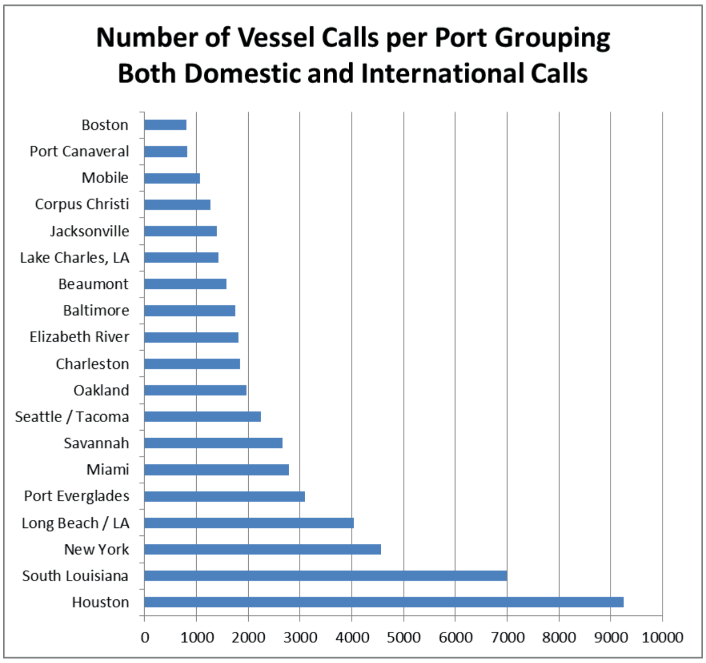


Figure 5: *Major US ports by vessel calls*

For some of the major ports the destination ports are presented for the routes with more than 50 annual calls. Figure 6 shows the domestic traffic routes for Houston, South Louisiana, New York and Savannah.

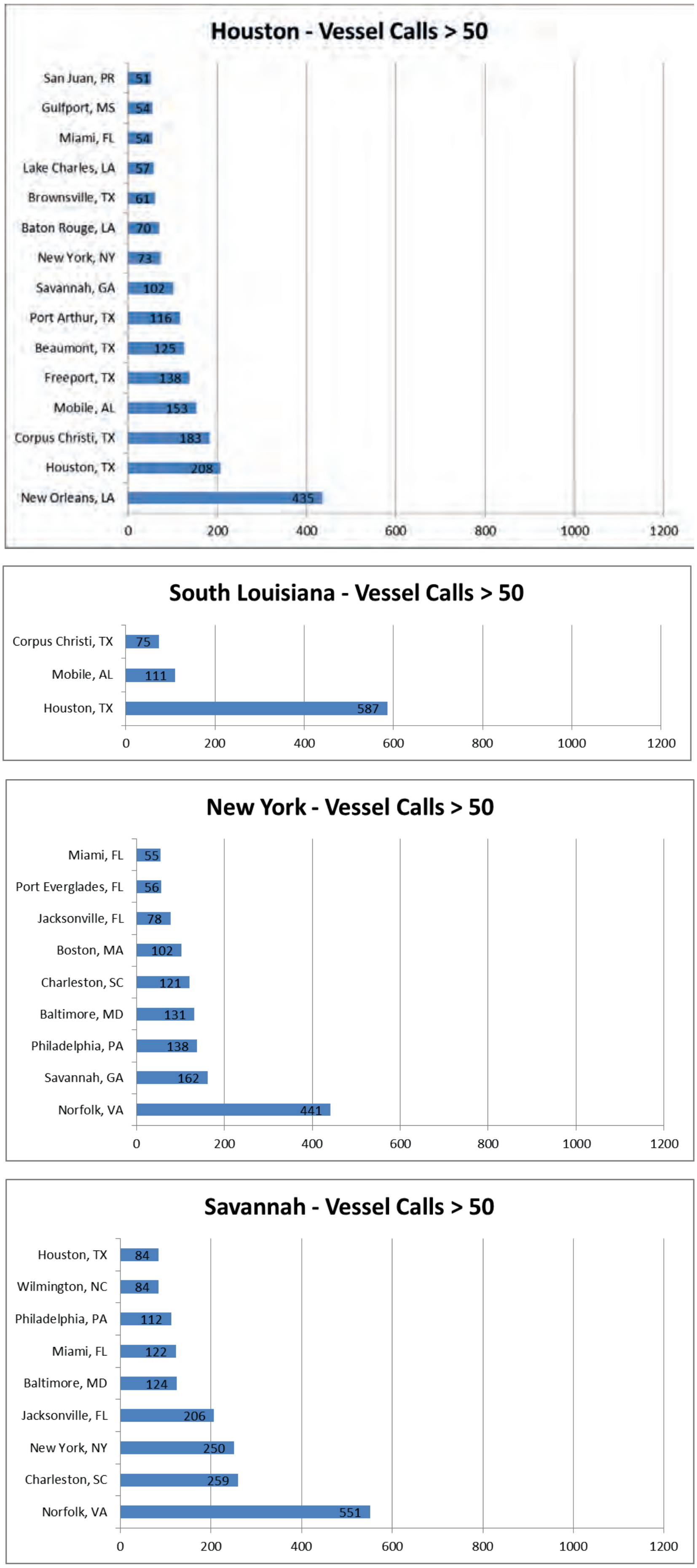


Figure 6: *Domestic routes for major US ports by vessel calls*

The data can also be used to analyse the ship type traffic between the ports, and as an example the ship types between the South Louisiana and Houston is shown in figure 7.

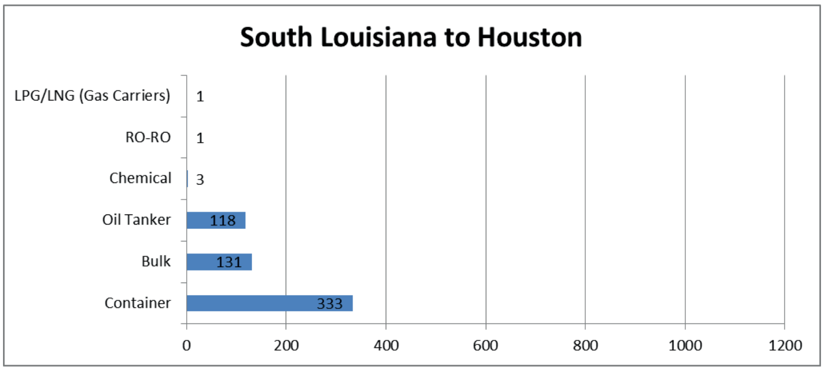


Figure 7: *Vessel traffic South LA to Houston*

The international routes between the ports can also be presented and traffic between Houston and Mexico is shown in figure 8 (Houston to Tampico, Puerto Madero and Altamira).

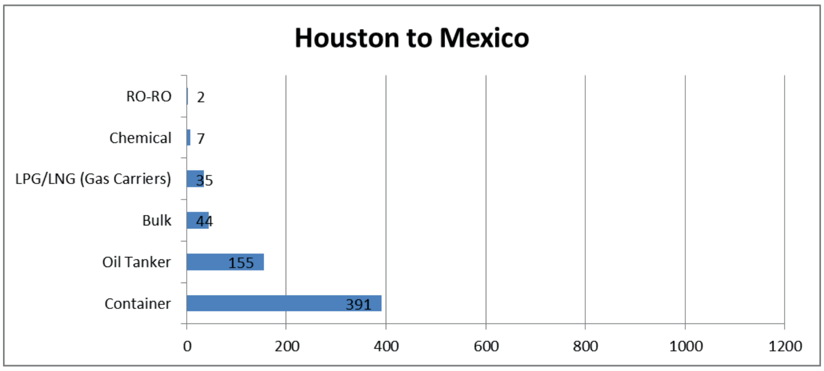


Figure 8: *Vessel traffic Houston to Mexico*

There are also other studies of the ship traffic into the North American ECA. The report for IMO in regards to the feasibility of LNG as a fuel for the Wider Caribbean Region (WCR) ECA[3] analysed the RAC-REMPETIC Caribe GIS database for maritime traffic in the Wider Caribbean Region. The results are also of interest for this study because of the large amount of traffic between the North American ECA and the WCR ECA.

The West Coast Marine Liquefied Natural Gas (LNG) Supply Chain Joint Industry Project[4] evaluated the vessel calls on the Canadian West Coast and in the Pacific Northwest where there is also high ship traffic intensity.

2.3 Main shipping segments

The following describes the features of the main shipping segments worldwide, and the current size and order book of the international fleet. The current interest and adoption of LNG as a fuel for each segment both internationally and in North America are also discussed.

2.3.1 Oil tankers

This market segment makes up the single largest ship type in the world due to the preponderance of the transport of petroleum products. Both Clarkson's and Fairplay continue to rate the tanker market as sluggish in the near term. With some experts predicting an increase in oil imports to Asia of around 9% and a decrease in imports in the United States of around 7% in the near term, the number of tankers is expected to stay flat.[1] The current disposition of the international fleet is shown in table 1. The current number is the estimated total number of ships actively trading, while the world order book is the estimated number of new builds contracted for delivery in the next 1 to 4 years. If one considers that the economic life of a ship is 20 to 30 years, then the world order book is a good indicator of how the industry views the market outlook for that vessel type over the next several decades.

[1] Clarkson's Shipping Review and Outlook, September 2012.

Table 1 – *World tanker fleet. Data courtesy of Clarkson's Shipping Intelligence*

World Tanker Fleet		
Type	**Current number**	**World order book**
VLCC	625	56
Suezmax	493	55
Aframax	911	84
Panamax	414	26
Handy	2,594	263
Small <10K	6,287	171
Tankers total	**11,320**	**655**

Thus far no crude carrier has been powered by LNG, but there are concepts such as DNV's **TRIALITY** VLCC (figure 9).

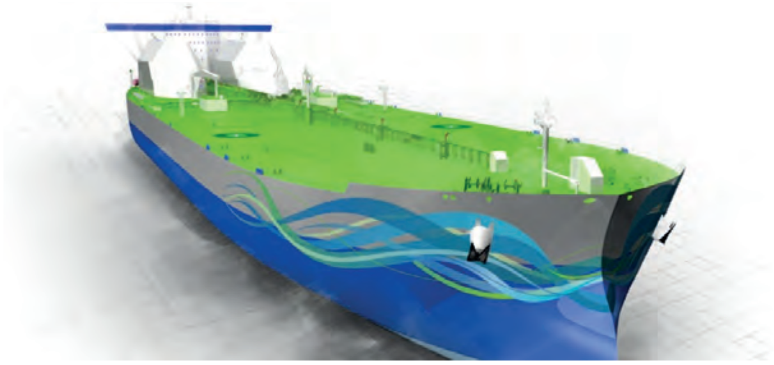


Figure 9: *DNV's **TRIALITY** concept for an LNG fuelled VLCC*

However, there is currently one product tanker operating with LNG as a fuel and it is the **BIT VIKING**. The vessel was converted in 2011 and is using dual fuel main engines that can operate on either gas or diesel fuel. The vessel is operating in the North Sea (figure 10).

Figure 10: ***BIT VIKING** LNG fuelled product tanker*

In addition, there has also been a contract signed for the delivery from a US shipyard of up to six 50,000 DWT LNG ready product tankers for the US market. The construction of these Jones Act vessels is slated to start in the fourth quarter of 2015. The shipyard's image of the tankers is shown in figure 11.

Figure 11: *LNG ready US Jones Act product tankers (Photograph reproduced courtesy of NASSCO)*

2.3.2 Bulk carriers

Bulk carriers make up a large portion of the world fleet. Like tankers these are typically large, slow speed, relatively simple ships. The current disposition of the fleet is shown in table 2. The market outlook for bulk carriers is expected to be 2% to 4% growth in the near term giving very modest growth in the fleet. Bulk carrier owners are also facing a tough financing environment slowing growth in this segment.

Table 2 – *World bulk carrier fleet. Data courtesy of Clarkson's Shipping Intelligence*

World Bulk Carrier Fleet		
Type	**Current number**	**World order book**
Capesize	1,547	255
Panamax	2,288	455
Handymax	2.890	546
Handy size	3,022	384
Total	**9,747**	**1,640**

There are no large size bulk carriers that are being powered by LNG, but there have been some concept designs that have been developed. The ECO-ship 2020, an open hatch bulk carrier, and ECORE, a Very Large Ore Carrier (VLOC), are concept designs using LNG as a fuel that have been developed by industry partners, including DNV. Images of the two concept designs are shown in figure 12 and figure 13.

Figure 12: *Concept design DNV and* ***Oshima*** *ECO-ship*

Figure 13: *Concept design ECORE VLOC*

In North America, the bulk carriers operating on the Great Lakes are considered likely candidates for using LNG as a fuel and the first projects for converting existing vessels have been recently announced. Interlake Steamship Co., a US company that owns eight self-unloading ore carriers operating on the Great Lakes, has announced its intention to convert seven of the vessels in the fleet to use LNG as the main propulsion fuel. The first vessel planned to be converted is the **M/V MESABI MINER**.

2.3.3 Container ships

Since the first container ship liner service from the US to Rotterdam in 1966, this market segment has grown tremendously. These ships range in size from a feeder vessel, of few hundred containers, to the Ultra Large Container Vessels (ULCV) of over 18,000 TEUs. These are typically large, fast and complex ships generally operated on a liner service. The world container ship is broken down by size as follows:

Table 3 – *World container ship fleet. Data courtesy of Clarkson's Shipping Intelligence*

World Container Ship Fleet		
Type	**Current number**	**World order book**
Post Panamax 8000 TEU+	529	248
Post Panamax 3-8000 TEU	619	97
Panamax 3–5000 TEU	915	13
Sub Panamax 2–3000 TEU	667	44
Handy 1–2000 TEU	1,230	65
Feeder 100–1000 TEU	1,165	9
Total	**5,125**	**476**

This market segment is expected to see significant growth in the use of LNG fuel; however, the challenge for ships on longer voyages will be the increased cargo space that must be converted to fuel storage to give a sufficient range. Figure 14 below illustrates two of the recent concept designs put forth by DNV and GL.

Figure 14: *GL's LNG powered container feeder concept, DNV's QUANTUM large container concept*

In North America, the container ship segment has recently seen several announced projects in converting existing vessels, as well as new builds with LNG as the fuel. The US based company TOTE Inc. has recently ordered the conversion of the two existing ro-ro ships which operate between Pacific Northwest (Tacoma, WA) and Alaska. The company has also signed a contract with a US shipyard for the new construction of two 3100 TEU ships with an option for three more. These Jones Act (see section 2.4.2 for explanation of the Jones Act) container ships are intended for the USA to Puerto Rico trade and are expected to be powered by MAN Diesel two stroke dual fuel engines (figure 15).

Figure 15: *TOTE LNG fuelled container ships (Image reproduced courtesy of* ***TOTE****)*

Another US company, Matson, has also signed a contract with a US shipyard for the construction of two 3600 TEU container ships equipped with dual fuel engines. These are also Jones Act vessels and are intended for trade from the US West Coast to Hawaii. A rendition of the vessels is shown in figure 16.

Figure 16: ***MATSON ALOHA*** *Class container ship (Image reproduced courtesy of Matson)*

Crowley Maritime has also confirmed a project to build two LNG fuelled ConRo ships with DNV class at a US shipyard. These are also Jones Act vessels and are intended for the USA to Puerto Rico trade (figure 17).

Figure 17: *Crowley Commitment Class ConRo vessels*
(Image reproduced courtesy of Crowley Maritime Co.)

In addition, Horizon Lines have announced plans to convert the power plants on two of its steam turbine cargo vessels and install dual fuel engines. The United States Coast Guard (USCG) has completed a pre-determination that this conversion could be done in a non-US shipyard without jeopardizing the Jones Act status of the vessels.

2.3.4 Offshore supply and support vessels

This is another market segment where interest in LNG fuel is high. Significant investment has been made with twelve OSVs currently operating in the North Sea with LNG as a fuel and an additional ten vessels on order worldwide as on 1 November 2013. Six of the ordered OSVs are being built in the US and will be operated in the Gulf of Mexico by Harvey Gulf Offshore. The current make-up of the world offshore vessels is presented in table 4.

Table 4 – *World offshore support vessels*

World Offshore Support Vessel Fleet		
Type	**Current number**	**World order book**
AHTS	2951	212
Crew Boat	653	222
Drill Ship	82	100
Pipe lay	42	
PSV	855	417
Multi-Purpose	331	
ROV	34	
Diving Support	104	
Heavy Deck/Lift	292	No data available
Survey/Research	1043	No data available
Total	**6387**	**951**

The figure below is an illustration of the OSVs being built by Harvey Gulf. The first vessel is expected to be delivered in the first quarter of 2014.

Figure 18: *An illustration of Harvey Gulf's LNG powered OSVs (Image reproduced courtesy of Harvey Gulf)*

2.3.5 Passenger and cruise vessels

The first LNG fuelled vessel was a car ferry in Norway, and of the current fleet of LNG fuelled ships the passenger coastal ferry segment is still the largest. The option of using LNG as a fuel is attractive to these types of vessel, because of the operating profile as well as for economic, regulatory and environmental reasons.

In North America, the Canadian ferry operator Société des traversiers Québec (STQ) has ordered three LNG fuelled car ferries to be used on the St Lawrence waterway. There are two different new building projects, with one LOA 130 m ferry being built at an Italian shipyard, and the two other LOA 92 m ferries to be built at a Canadian shipyard (figure 19).

Figure 19: *Renditions of Société des traversiers Québec LNG ferries*

In addition, BC Ferries and Washington State Ferry system, which are operating large ferry networks in the Pacific Northwest, have shown considerable interest in the use of LNG as fuel for both its existing vessels as well as for future new building projects.

The cruise ferries are another ship type where LNG as a fuel is used and is expected to see more growth. Viking Line is operating the largest LNG powered passenger ship to date between Stockholm and Helsinki in the Baltic Sea. The vessel entered service in January 2013 and is a combination roll-on/roll-off and passenger ferry (figure 20).

Figure 20: ***VIKING GRACE*** *with external LNG tanks (Image reproduced courtesy of Marine Insight.com)*

Another cruise ferry in service with gas fuelled engines is the **MS STAVANGERFJORD**, operating between Norway and Denmark with a sister ship under construction (figure 21).

Figure 21: *Fjord Line's* ***MS STAVANGERFJORD*** *(Image reproduced courtesy of Fjordline.com)*

For the cruise vessel segment, the option of using LNG is also a very relevant and attractive option, especially since most of the cruise vessels operate inside the ECAs for a majority of the time.

AIDA Cruises is expected to be the first cruise line to use dual fuel engines for its two new dedicated cruise ships being built in Japan. Other cruise lines are also considering the use of LNG as a fuel for new building projects. For the existing vessels, the cruise lines are also evaluating different compliance options to meet the SO_x requirements inside the NA ECA. The cruise industry is considering the use of LNG powered barges to supply shore power when in US port, so called 'cold ironing' barges.

In the US, EPA did not accept a proposal from the cruise industry to use an averaging scheme to meet the ECA requirements. Some of the major cruise lines have decided to install exhaust gas scrubbers in the near and medium future in order to comply with the requirements for SO_x emissions.

Carnival Corp. has been given a conditional acceptance from the EPA and USCG, as US port state representatives, for a programme to develop and apply scrubber technology as a method for NA ECA compliance. This technology will incorporate removal of SO_x as well as reduction of particulate matter from the diesel engine exhaust gas. The exhaust gas cleaning systems will be installed on 32 ships belonging to Carnival Group that have significant operations inside the North American ECA at a price of $1m to $1.5m per engine. A trial of these systems will cover several engine types, sizes and configurations, and installations will occur during regular dry dockings from 2014 into early 2016.

Despite the recent incidents such as the **COSTA CONCORDIA** and **CARNIVAL TRIUMPH** that have negatively affected the reputation of the cruise industry, the market outlook for cruise ships is quite good with modest growth in the fleet expected.

The current cruise fleet and order book is listed in table 5.

Table 5 – *World cruise ship fleet and order book. Data courtesy of Clarkson's*

World Cruise Ship Fleet		
Type	**Current number**	**World order book**
Passenger vessels	1,313	71
Cruise ship	368	25
Total	**1,681**	**96**

2.3.6 Refrigerated cargo ships and car carriers

Although these two market segments are quite small and no LNG powered ships have been reported, these ships would likely benefit from the use of LNG fuel and may see some interest in the future. The refrigerated cargo market has declined in recent years due to the ability of container ships to haul refrigerated containers, but there are still 871 ships actively trading. The car carrier market, on the other hand, is expected to see modest growth over the next several years. The current number of each vessel type and world order book is shown in table 6.

Table 6 – *World fleet of reefer ships and pure car carriers. Data courtesy of Clarkson's*

World Reefer and Car Carrier Fleet		
Type	**Current number**	**World order book**
Reefer ship	871	2
Car carrier	754	62
Total	**1625**	**64**

2.3.7 LPG/LNG

LNG carriers have been using LNG for fuel since the earliest days of the trade. When steam turbines were the propulsion system of choice, boil off from the cargo was piped to the boilers and burned to produce steam for propulsion. Most modern LNG tankers now use dual fuel diesel engines that can burn any combination of LNG and marine bunkers. The use of cargo boil off for fuel will preclude LNG tankers from taking separate LNG bunkers and hence this is not expected to be a market for LNG bunkering in the future. The current fleet and order book is listed in table 7.

Table 7 – *World LNG/LPG fleet and order book. Data courtesy of Clarkson's*

World Reefer and Car Carrier Fleet		
Size (m^3)	**Current number**	**World order book**
LNG	379	115
LPG >5000 cu.m	606	116
Total	**985**	**231**

There has been some recent activity in the Liquefied Petroleum Gas carrier segment (LPG). Anthony Veder Inc. has ordered two small LNG powered ethylene carriers for service in the North Sea. This segment may see some conversions and new building with LNG fuel in the next 15 years.

2.4 North American shipping and domestic fleets

The Canadian and USA flagged vessels can be considered for the purpose of this study as the North American domestic fleet. The large majority of these vessels are not engaged in international shipping, but are used for waterborne transportation and services within and between the respective navigable waterways of the two countries. However, this means that this fleet will operate within the NA ECA and that the demand for LNG from the domestic fleet will be an important factor in the availability of LNG and bunkering facilities for the international shipping coming in and out of the NA ECA.

2.4.1 US domestic shipping

In 2011, US waterborne trade (foreign and domestic) amounted to over 2.1 billion metric tons. Domestic trade accounted for about 0.8 billion metric tons of the total with over 70% transported on the Great Lakes and inland waterways.[5]

The trend in the waterborne commerce of the US in million short tons is shown in figure 22.

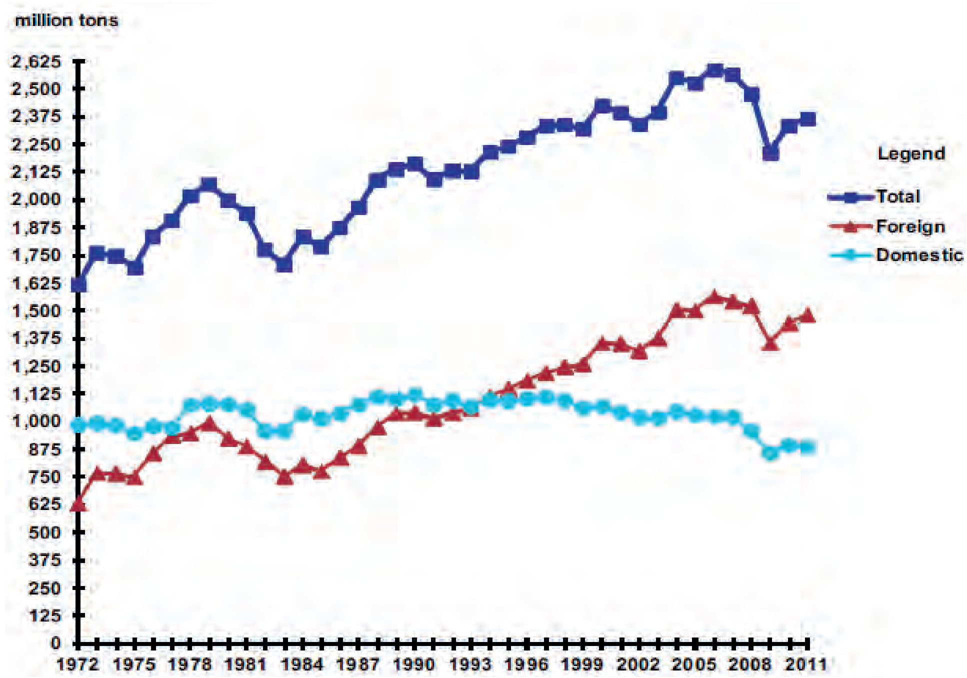


Figure 22: *Waterborne commerce of the USA*

It is seen that the domestic waterborne commerce has had a slight decrease over the last 20 years and that growth has been in the foreign trade. The domestic waterborne commerce is dominated by barge traffic which in 2011 accounted for about 80% of the total.

The waterborne trade between the US and Canada was about 70 million metric tons in 2011, which is less than 10% of the US domestic waterborne trade.

The transportation in US is also characterized by a range of relatively small ports rather than a few big ones; the largest port, Port of South Louisiana, represents only about 7% of the total trade volume. This is unlike Canada and other parts of the world where just a few large ports represent the major share of total trade.

2.4.2 US domestic fleet

The US domestic fleet numbers more than 40,000 watercrafts, primarily tugs and barges. The Merchant Marine Act of 1920, also known as the Jones Act, is a United States federal statute that provides for the promotion and maintenance of the American merchant marine. Among other purposes, the law regulates maritime commerce in US waters and between US ports. Section 27 of the Jones Act deals with cabotage (i.e. coastal shipping) and requires that all goods and passengers transported by water between US ports be carried on US flag ships, constructed in the United States, owned by US citizens, and crewed by US citizens and US permanent residents.

The fleet of US flag and Jones Act vessels supports the domestic trade and movement of some 90 million passengers.[2] The actual fleet of ships, however, is quite small. The breakdown of the US flagged vessels and the Jones Act authorized ships are shown in table 8. When dry and tank barges are removed, there are about 7,000 Jones Act vessels, of which 80% are tugs.

Table 8 – *US owned and Jones Act vessels. Data courtesy of MARAD & Clarkson's*

US Flagged Vessels	
Ocean	**179**
Tankers	49
Dry Bulk	6
Container	29
Ro-ro	32
ITB	2
General	21
Coastal	**39,620**
Tugs	5,735
Dry barge	27,483
Tank barge	4,731
Offshore	1,067
Ferries	604
Total	**39,799**

Jones Act Vessels	
Ocean-going vessels	90
Lakers	48
Tugs	5,735
Dry Barge	27,483
Tank Barge	4,731
Offshore	525
Ferries	604
Total	**39,224**

2.4.2.1 *Offshore support vessels*

From the Clarkson's vessel database the current fleet of US flagged offshore support vessels is broken down as follows:

Table 9 – *Breakdown of US OSV fleet. Data courtesy of Clarkson's*

US Offshore Fleet		
Type	**Current number**	**World order book**
OSV/PSV	573	70
AHT/S	105	1
Crew/Workboat	218	6
Survey	107	4
Diving, ROV support	17	6
Oil Response, Well, Misc.	47	–
Total	**1,067**	**87**

[2] MARAD US-Flag Waterborne Domestic Trade and Related Programs.

Most of these vessels fall into the crew/fast supply category and are 50 m (164 ft) in length or less. According to Marcon International Inc., a vessel chartering and brokerage firm, there are 199 platform supply vessels and anchor handling vessels currently operating in the Gulf of Mexico with a length greater than 55 m (180 ft). It is expected that offshore supply vessels able to utilize LNG fuel will be in the 60 m and up range for length. As an example, the six ordered LNG fuelled OSVs for Harvey Gulf are 95 m in length.

The offshore vessels serve 31 floating drilling units, 29 jack-ups and 9 platform rigs. The outlook for the Gulf of Mexico oil and gas production is optimistic with the number of rigs expected to increase in the future. This will require a larger OSV fleet with larger vessels able to support deep water rigs and it is expected that a significant portion will be LNG powered.

2.4.2.2 *Container*

There are currently 69 US flagged container vessels according to MARAD. Of these vessels, 26 are Jones Act ships. The single largest fleet of US flagged vessels is the 56 container vessels managed by Maersk Line, a subsidiary of A.P. Moller Maersk Group, to provide the US government with logistical support. As indicated for the international fleet, LNG fuel is expected to be an attractive option for container ships. As discussed in section 2.3.3, there have been several conversion and new build contracts announced in the US and continued interest in LNG fuel from the domestic container ship segment is expected, but the relative small number of ships in operation will have limited impact on the overall demand of LNG as a fuel for shipping.

2.4.2.3 *ATBs, tugs, and pushboats*

In the US domestic market these vessels make up the largest class of ships. According to MARAD, it is estimated that there are 5,735 tugs and pushboats operating in US ports and inland waterways. Although challenges exist for the implementation of LNG fuel for these vessels, the benefits in operating costs and emissions reductions have attracted the attention of operators. There are no confirmed contracts announced in the US for any LNG fuelled vessels in this segment; however, Shell has issued a request for the design and construction for LNG bunker barges for the US market.

Two examples of the international activity in this segment are shown below in figure 23. The first example is the two Greenstream and Greenrhine barges which have been chartered by Royal Dutch Shell to transport liquid fuel on the river Rhine.

The second design is the first LNG fuelled tug and is being built at a Turkish shipyard for delivery to the Norwegian tug owners Bukser & Bergnings AS. Two tugs are on order, and the first vessel is expected to be delivered by the end of 2013.

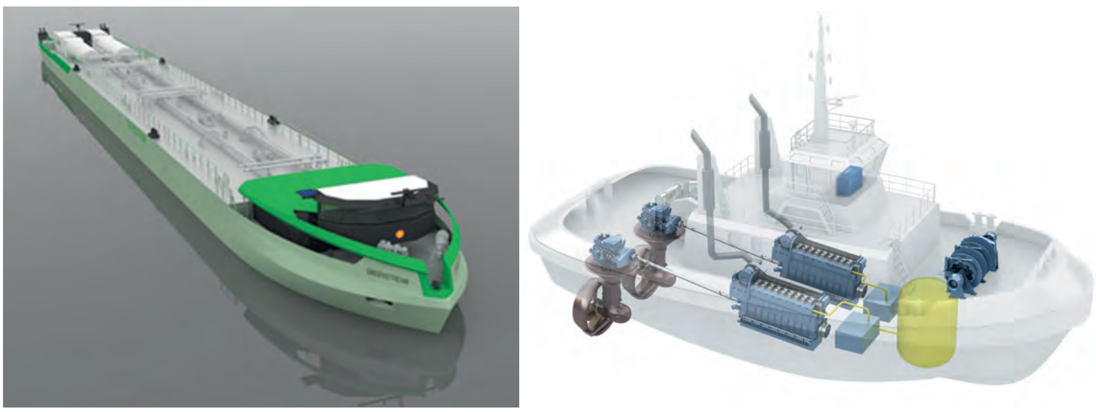


Figure 23: *LNG powered tank barge and LNG fuelled tug for B&B (Image reproduced courtesy of Tradewinds)*

2.4.2.4 *Tankers*

Oil and product tankers are a significant portion of the US flagged ocean going fleet engaged in domestic trade. The figure below is the current fleet and order book.

Table 10 – *Breakdown of US tanker fleet. Data courtesy of Clarkson's*

US Tanker Fleet		
Type	**Current number**	**World order book**
Product/Chem. carriers	33	10
Shuttle Tankers	2	–
Oil Tanker	14	2
Total	**49**	**12**

The US tanker and product tanker segment have shown some interest in the option of using LNG to comply with the ECA requirements.

Shuttle tankers are necessary when an FPSO is used to produce an oil or gas play in deep water. These tankers remove the accumulated oil from the FPSO and transfer it to shore. Generally, each FPSO requires two shuttle tankers. There are currently only two shuttle tankers operating in the Gulf of Mexico, but this number is expected to increase as exploration and production moves into deeper water and the use of an FPSO becomes more attractive. Due to their operating profile of making short trips to fixed ports and operating mostly in an ECA, this market segment is expected to see growth in the use of LNG fuel.

2.4.2.5 *Ferries*

According to MARAD there are currently 576 ferries in the United States. Most of these ferries are owned and operated by a local or regional public transportation office. Many ferries are relatively small and serve crossing of rivers and lakes. The Washington State Ferry (WSF) system in the Pacific Northwest and the Alaska Marine Highway System operate large and extensive coastal ferry networks and as mentioned in section 2.3.5, WSF has announced its intention to use LNG as fuel. WSF recently announced that a waterway suitability assessment (WSA) was submitted to the USCG. The proposal calls for converting six of its Issaquah Class vessels to be fuelled by LNG. In 2013, DNV completed a safety and security plan, risk assessment and operational manual for converting to LNG.[5] Pending US Coast Guard approval and state funding, WSF could begin the first conversion of the Issaquah Class ferry as early as 2016.

An image of the converted ferry, showing the location of the LNG tank, is shown in figure 24.

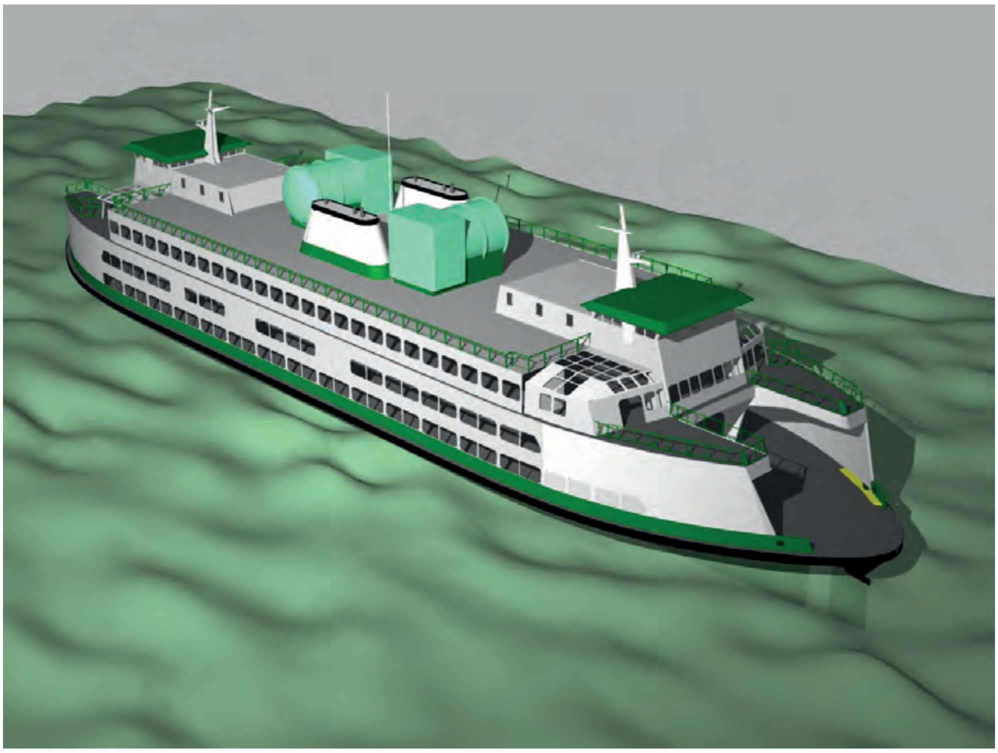


Figure 24: *Rendering of LNG tanks on an Issaquah class (Image reproduced courtesy of WSF)*

Additionally, the Staten Island Ferry, which operates nine passenger only ferries in New York, has planned to convert at least one of its ferries to operate on LNG.

2.4.2.6 *Lakers*

A special type of vessel are the cargo ships operating on the Great Lakes. These are vessels transporting iron ore, coal, limestone and other commodities between the US and Canadian ports on the Great Lakes. The vessels typically operate from April until December each year when the ports are ice free.

The US flagged share of these vessels consists of 46 self-propelled vessels and 10 tug/barge vessels. The majority of the self-propelled vessels are between 150 to 300 m in length. In addition to the environmental and possible economic benefits, since these vessels mostly operate on fixed routes and ports, the availability of LNG bunkering facilities will also enable the use of LNG.

The Interlake Steamship Co. which owns eight ore carriers operating on the Great Lakes intends to convert seven of its diesel powered vessels to dual fuel engines (figure 25).

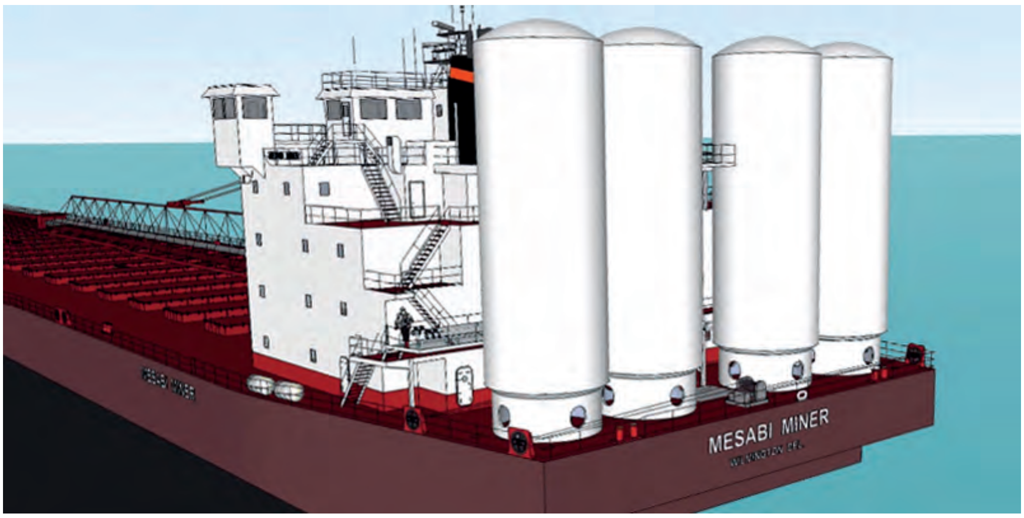


Figure 25: *Interlake Steamship Co. vessel to be converted to LNG (Image reproduced courtesy of HHP Insight)*

Other owners and operators of vessels on the Great Lakes are also exploring the option of using LNG as fuel.

2.4.3 Canada domestic shipping

The Canadian domestic waterborne transportation volume is smaller than in USA. In 2011, according to Statistics Canada, the total domestic volume was 125 million metric tons, which is about 15% of the US domestic waterborne volume. In addition comes about 95 million tons of trade between the two countries. The larger share of the domestic cargo is transported along the Atlantic coast; the rest is distributed between the Pacific coast and the Great Lakes.

2.4.4 Canadian domestic fleet

The Canadian domestic fleet consists of about a 1,000 vessels according to LR's SeaWeb. The grouping by major ship type is shown in table 11.

Table 11 – *Canadian flagged fleet (LR SeaWeb)*

Canadian Flagged Vessels	
Ocean + Lakers	**260**
Tankers	27
Bulk, Gen Cargo	96
Container	1
Ro-ro & Passenger	94
AHTS/OSV	37
Ice breaker	5
Coastal	**646**
Tugs, ATB	210
Fishing	275
Barges, non-propelled	83
Passengers	58
Research/Survey	20
Total	**906**

2.4.4.1 *Offshore support vessels*

From the Clarkson's vessel database the current fleet of Canadian flagged offshore support vessels are broken down as follows:

Table 12 – *Breakdown of Canadian offshore fleet. Data courtesy of Clarkson's*

Canadian Offshore Fleet		
Type	**Current number**	**World order book**
OSV/PSV	5	–
AHT/S	26	–
Crew/Workboat	2	–
Survey	7	–
Oil Response, Well, Misc.	5	–
Total	**45**	

Many of these vessels operate on the Canadian Atlantic coast and support the offshore activities outside of Newfoundland. There have not been any confirmed plans for new build or conversion projects related to the use of LNG as fuel.

2.4.4.2 *ATBs, tugs, and pushboats*

The Clarkson's World Fleet Register lists a total 219 Canadian flagged tugs with 55 tugs having a gross tonnage of more than 400. In Canada there are no confirmed orders for LNG fuelled vessels in this segment; however, some Canadian designers are developing LNG fuelled tug designs.

2.4.4.3 *Tankers*

The Clarkson's World Fleet Register lists a total 29 Canadian tankers and the tanks fleet can be categorized in the figure.

Table 13 – *Canadian tanker fleet. Data courtesy of Clarkson's*

Canadian Tanker Fleet		
Type	**Current number**	**Order book**
Product/Chem carrrier	22	–
Shuttle tankers	4	–
Oil tanker	3	–
Total	**29**	

The fleet is primarily used for domestic transport of fuel and oil products to the Canadian Atlantic and Arctic coast. The shuttle tankers are used to service the oil production outside Newfoundland.

2.4.4.4 *Ferries*

The Clarkson's World Fleet Register lists a total of 138 ferries and Ro-Pax operating with Canadian flags. A total of 66 ships are listed with a passenger capacity above 200. The BC Ferries on the Canadian West Coast operates about 35 of the listed ships. As noted in section 2.3.5, Société des traversiers Québec (STQ) has ordered three LNG fuelled car ferries to be used on the St Lawrence waterway.

BC Ferries has expressed interest in the use of LNG and has recently issued a request for proposal (RFP) for three vessels with several propulsion options, including both LNG and conventional fuels. BC Ferries has stated while they do intend to acquire LNG fuelled vessels, further technical and financial analyses is required.

Seaspan Ferries Corp. which operates trailer ferry service to Vancouver Island will also explore the use of LNG as a fuel for their fleet renewal project.

2.4.4.5 *Lakers*

The Canadian flagged cargo vessels operating on the Great Lakes and the St Lawrence Seaway consist of about 60 ships. The great majority of these vessels is bulk carriers, but also includes about ten tankers and a few ro-ro/container ships. Two of the major Canadian owners operating vessels on the Great Lakes and St Lawrence Seaway, CSL Group and Algoma Central Corp., have about ten vessels on order.

3 Key trends in NA ECA

3.1 General trends

The main drivers for the use of LNG as a fuel on board ships are the financial benefits and the environmental regulations, both internationally and regionally.

Most ships and marine vessels currently use petroleum based liquid fuels, either distillate fuel or residual fuel. Since the combustion of these fuels contributes to the emissions of substances that are found to be harmful to the environment, the use of these fuels will be subject to restrictions in the coming years. The introduction of the North American ECA is one of the major initiatives taken by IMO and the member states in order to reduce the environmental impact of international shipping.

Another development is the increased availability of natural gas in North America because of the extraction of natural gas from shale formations. It is expected that by 2035 53% of the natural gas consumed in the United States will come from shale gas compared to 20% in 2010.[6] The increased supply of natural gas in North America has been followed by a decrease in the natural gas price which has made the option of using natural gas as a fuel financially more attractive both for ships and for the transportation sector in general.

The increased production of natural gas in North America combined with the large amount of known recoverable shale gas resources has also initiated a number of projects related to the export of LNG from North America. Several marine terminals originally built to import LNG are planned for conversion to exporting LNG. A consequence from this is that in most cases a natural gas liquefaction plant will have to be built near or at the terminal, and this will have the potential to increase the supply of LNG available as a fuel for ships.

International shipping in and out of North America in terms of cargo volume is expected to increase modestly towards 2020 (IHS 2012). This is also reflected in the projections in the United States fuel demand for domestic and international shipping. According to the EIA, the annualized growth in the fuel demand for domestic and international shipping is expected to be 0.5% and 0.1%, respectively through 2035.

In North America there is also a strong interest and a potential large market for the use of LNG as a fuel for on-road and rail transportation. This is primarily driven by the potential savings in fuel cost, but the environmental benefits are also important. The demand for this multi-modal use of LNG as a transportation fuel is an additional incentive for the development of an LNG supply chain in North America.

3.2 Environmental requirements

The shipping industry has to comply with a number of regulations pertaining to the prevention of pollution and the emission of potentially harmful substances to the environment. IMO is the international agency responsible for issuing and adopting regulations applicable to international shipping. The IMO member states are responsible for implementing the regulations.

In addition to the international regulations, there are national and regional regulations that might apply to vessels both inside and outside of the ECA. In Canada, Transport Canada (TC) is the federal agency in charge of environmental regulations which applies to the maritime sector.

In the US, the Environmental Protection Agency (EPA) is the agency that develops and enforces federal environmental regulations based on the laws passed by the US Congress. The responsibility of EPA also includes the regulatory oversight of the emissions from ships and marine vessels, including the IMO MARPOL Annex VI regulations. The United States Coast Guard (USCG) is responsible for enforcement of the international and national maritime regulations pertaining to ships and marine vessels.

The international regulations and initiatives from IMO to reduce the negative impact of the air emissions from shipping are focused on the following:

– SO_x *reduction & Particulate Matter (PM)*

  Diesel fuel contains sulphur which is released to the atmosphere as Sulphur Oxides (SO_x) after the fuel has been burned in engines and boilers. Airborne SO_x have been found to have a negative impact on public health and formation of acid rain. Reduction in SO_x emissions can be achieved by using diesel fuels with a low sulphur content, exhaust gas treatment (scrubbers), or the use of alternative fuel, e.g. natural gas, with very low or negligible sulphur content. PM emissions are expected to decrease when the sulphur content of the fuel is reduced.

– NO_x *reduction*

  Nitrogen Oxides (NO_x) are also considered harmful substances, causing local pollution and adverse effects on public health. NO_x are formed during the combustion process in an engine when the Nitrogen and Oxygen in the air is reacting and is very dependent on the combustion process, especially the temperature and pressure. The amount of NO_x formed during combustion can be reduced by some extent by engine design and optimization of the combustion process. Further reductions can be achieved by Exhaust Gas Recirculation (EGR), Selective Catalytic Reactor (SCR) in the exhaust system, and different methods for introduction of water into the combustion process.

– *Energy efficiency and* CO_2*/GHG emission*

  The reduction of CO_2 emissions is intended to mitigate the impact of Green House Gas (GHG) emissions from shipping. The current approach from IMO is to improve the energy efficiency of new ships by setting more stringent design requirements and stimulate more energy efficient operational practices.

It is noted that specific limits for emissions of Particle Matters (PM) and Hydrocarbons (HC) are not given in the IMO MARPOL Annex VI regulations.

However, in the US, EPA has regulated the emissions from diesel engines to be installed on US flagged vessels, Federal Marine Compression-Ignition (CI) Engines – Exhaust Emission Standards. These regulations include limits on PM and HC emissions on new Category 1 and 2 engines, which are defined as engines with displacement volume per cylinder < 7 litres and displacement volume per cylinder < 30 litres, respectively.

The EPA has also defined marine Category 3 engines, those with displacement volume per cylinder above 30 litres, and these engines are required to meet equivalent standards to MARPOL Annex VI. In addition, the US is finalizing standards for Category 3 engines to control hydrocarbons (HC) and carbon monoxide (CO), as well as monitoring of particulate matter (PM) emissions.

The EPA regulations have also been implemented in Tiers, and more stringent Tier 3 and Tier 4 are being introduced in the coming years.

EPA has indicated that US flagged vessels with Category 1 or 2 engines can be designated as Ocean Going Vessels (OGV) if they operate extensively offshore. In that case, the engines can comply with MARPOL Annex VI as an alternative to meeting the more stringent EPA designated tier requirements.

Category 1 and 2 engines on a US flagged vessel that are not an OGV are required to meet the more stringent EPA 2008 Final Rule. However, EPA has indicated that Category 1 and 2 engines on vessels with Category 3 engines be allowed to comply with MARPOL Annex VI.

The goal of the introduction of ECAs in certain regions is to achieve a more significant local reduction in the emissions of SO_x and NO_x from shipping because of the intensity of the maritime traffic as well as the sensitivity of the area to harmful pollution to the atmosphere.

The requirements in MARPOL Annex VI applicable to the ECAs are intended to reduce both the SO_x/PM emissions and NO_x emissions from ships when operating within the ECA.

The existing and upcoming limits on the fuel oil sulphur content that is burned on all ships subject to the regulations in MARPOL Annex VI is shown in figure 26.

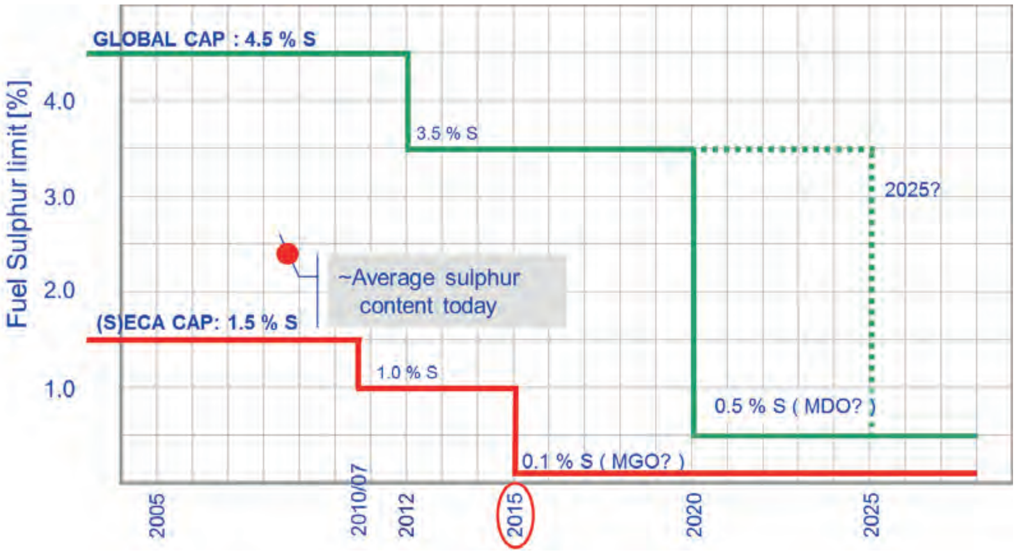


Figure 26: *Limits of sulphur content in fuel oil*

It is seen that the next milestone is coming on 1 January 2015 when the 0.1% limit on the sulphur content of fuel oil used inside the ECAs enters into force. In 2020, the global limit on sulphur content will be reduced from 3.5% to 0.5%. The date of the implementation of the global sulphur limit of 0.5% is subject to a review by IMO in 2018. The implementation of the 0.1% sulphur limits inside the ECAs will go forward even if the introduction of the 0.5% global limit is postponed until 2025. However, should the global limit of 0.5% be postponed, it is likely that this will decrease the number of LNG fuelled ships. This was one of the scenarios used for the modelling of the technology outlook in the DNV report Shipping 2020.[8] EU has also indicated that they will go ahead with 0.5% limit in non-ECA EU waters even if the global limit should be changed following the review in 2018.

The majority of ocean going vessels are operating primarily on diesel fuels with sulphur content above the limits inside the ECAs as well as the planned future worldwide limits. Diesel fuel with high sulphur content is commonly referred to as residual fuels. In the 2nd IMO GHG Study[7] it was estimated that almost 80% of the diesel fuel used in shipping was residual fuel (table 14).

Table 14 – *Estimated marine fuel consumption in million tons*[7]

	Total fuel consumption			International shipping		
	Low bound	**Consensus**	**High bound**	**Low bound**	**Consensus**	**High bound**
Residual fuel	215	257	308	172	213	265
Distillate fuel	64	67	92	51	64	79
Slow-speed engines	181	215	259	144	179	223
Medium-speed engines	92	110	132	73	91	113
Boilers	7	8	9	5	7	8

Abatement technologies, e.g. exhaust gas scrubbers, are considered an equivalent measure and can be used as an alternative if the emissions are reduced to the level equivalent to the use of low sulphur fuel. However, the approval of abatement technologies are up to the flag States and some flag States might be reluctant to approve scrubbers or will have particular requirements in order to verify equivalence.

In regards to the NO_x emission, the NO_x emissions from engines covered by MARPOL Annex VI are to be below the applicable curve in figure 27. The date on the right refers to the date the keel was laid for the vessel (start of construction). Tier I and Tier II are global limits that came into force in 2000 and 2011, respectively. Tier III will come into force in January 2016, and reduces the NO_x emissions of engines operated inside an ECA with 80% compared to the Tier I limit. There is a proposal to IMO to postpone the implementation of the Tier III limit; however, both USA and Canada have indicated their intention to enforce the limits for new build ships trading in the NA ECA.

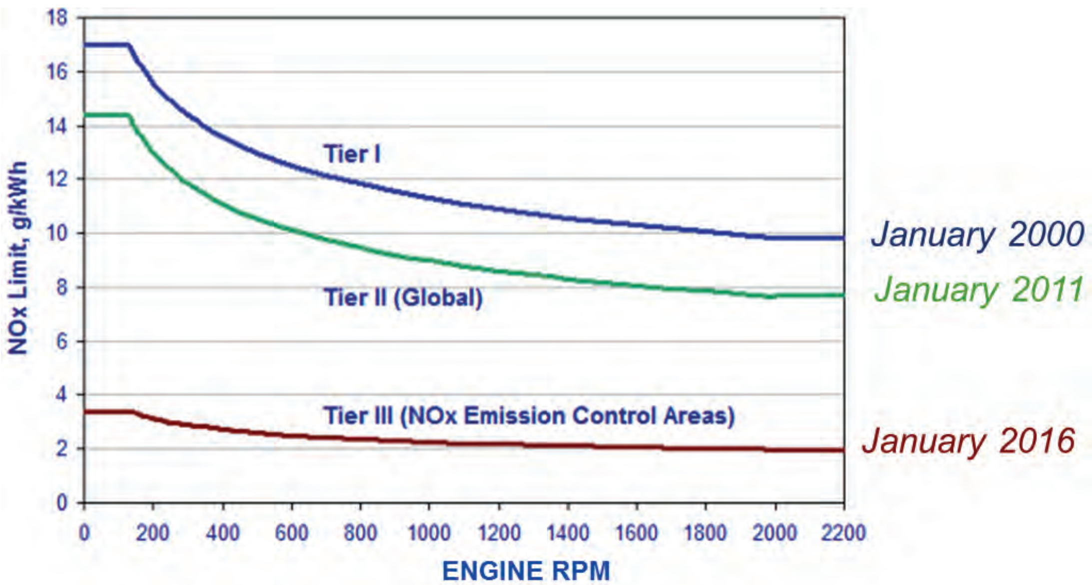


Figure 27: *Limits of NO_x emissions MARPOL Annex VI*

3.3 Technically feasible compliance strategies

In order to comply with the existing and future emission regulations and restrictions inside an ECA, the following options are available for vessels that are subject to the regulations in MARPOL Annex VI.

1. Use of low sulphur diesel fuel
2. Use of alternative fuels
3. Use of abatement technologies, typically exhaust gas treatment system

The options will be described and discussed in the following chapters comparing the features of each strategy in regards to the technical requirements, emission benefits and other considerations. It is also noted that a compliance strategy for a particular vessel or trade might involve a combination of all three options.

3.3.1 Low sulphur diesel fuel

The use of fuel inside the ECA with sulphur content below the allowable limit is frequently used on existing vessels and can also be considered as a viable option for ECA compliance, at least in the near future.

The term low sulphur fuel is an imprecise term, but has been commonly used to describe distillate fuel as opposed to residual fuel.

The term 'distillate' typically refers to light, refined diesel fuel with a sulphur content of 0.5% or less. This fuel is called marine gas oil (MGO) and ISO DMA. Marine diesel oil (MDO), ISO DMB, although inclusive of some residual content is also considered 'distillate' provided sulphur contents are below 0.5%.

The term 'residual' is used to refer to the lesser refined heavy fuel oils, which currently have sulphur contents on average of about 2.5%. Industrial names for the residual or heavy fuel oil (HFO) diesel grades are IFO180 and IFO380, correspondingly ISO RME25 and ISO RMG35.

Further definition and description of diesel fuels are as follows:

- IFO 380 – Intermediate fuel oil with a maximum viscosity of 380 Centistokes (<3.5% sulphur)
- IFO 180 – Intermediate fuel oil with a maximum viscosity of 180 Centistokes (<3.5% sulphur)
- LS 380 – Low-sulphur (<1.0%) intermediate fuel oil with a maximum viscosity of 380 Centistokes
- LS 180 – Low-sulphur (<1.0%) intermediate fuel oil with a maximum viscosity of 180 Centistokes
- MDO – Marine diesel oil
- MGO – Marine gas oil

– LSMGO – Low-sulphur (<0.1%) marine gas oil

– ULSMGO – Ultra Low Sulphur Marine Gas Oil – referred to as Ultra Low Sulfur Diesel (sulphur 0.0015% max) in the US and Auto Gas Oil (sulphur 0.001% max) in the EU.

In the following, the term low sulphur diesel fuel will be used to describe fuel oil in compliance with the ECA requirement and residual fuel will be used to describe fuel oil in compliance only with the global limit on sulphur content.

Using low sulphur diesel fuel to comply with the ECA requirements can be done in two ways:

– switch over to low sulphur diesel fuel from residual fuel when operating inside the ECA

– only operate on low sulphur diesel fuel both inside and outside the ECA

The first option is the most common compliance method currently used by the ocean going ships when entering the ECA and for vessels which are spending a limited time inside the ECA. It does require separate fuel storage tanks and transfer systems for low sulphur diesel fuel and residual fuel, but most vessels will have this arrangement in place. The switching does take some operational considerations with appropriate procedures in place, as there have been reported some issues with engine shutdown during switching operations. The fuel system and components need to be verified and modified as needed in order to ensure compatibility and reliable operation when operating on low sulphur diesel fuel. For low speed two-stroke engines, it can be necessary to evaluate the use of different cylinder lubrication oils when operating on different fuel oils for extended periods.

The second option is the simplest, but because of the higher cost of low sulphur diesel fuel it is expected to have a penalty of increased operating cost (OPEX). For vessels operating mostly inside the ECA, this option is a relevant compliance option.

Most of the smaller vessels inside the NA ECA and the inland waterways (e.g. tugs, workboats, ferries and fishing vessels) with medium and high speed engines are currently operating on low sulphur diesel fuel.

The use of low sulphur diesel fuel will ensure compliance with SO_x emission requirements, but the compliance with the upcoming restriction in NO_x emissions in the ECAs will not be met with the existing engine technology unless exhaust after treatment is used. Engine manufacturers are developing on-engine technology that is designed to comply with the stricter requirements on NO_x emissions. It is expected that this will involve Exhaust Gas Recirculation (EGR) in order to reduce the NO_x emissions to the IMO Tier III/EPA Tier 4 levels.

3.3.2 Use of alternative fuel

The use of LNG as an alternative fuel in order to comply with the ECA emissions restrictions is an option that is in use on existing vessels and planned for new vessels. Natural gas stored as LNG is the alternative fuel that is considered the most likely option in the short to medium future because of the available engine and system technology, class/statutory regulations, operational experience, fuel cost and availability of natural gas worldwide.

There are other alternative fuels that might become relevant options, including LPG, DME/Methanol, synthetic fuels and biofuels, but this study is limited to the consideration of LNG. The use of nuclear energy could also be considered as an alternative fuel; however, even with the existing development of small and modular nuclear reactors it is not considered a realistic option in the near future because of the cost, risk perception and regulatory challenges.

One of the major benefits of using natural gas as a fuel is that the emissions of SO_x and PM are negligible and NO_x emissions are reduced to below the IMO Tier III limits for Otto-cycle engines without the need for exhaust gas treatment system. The technology is available for many types of gas and dual fuel engines, as well as for the onboard gas storage and handling systems. The many years of experience with LNG carried as cargo on gas carriers where the boil off gas is used as fuel, have also enabled the maritime industry to build competence and develop standards that have been used as guidelines for the emerging use as LNG as a fuel for other vessel types.

The low price of natural gas compared to diesel fuel, especially in North America, is another reason for the considerable interest in the use of LNG as a fuel, even as there is some uncertainty in the 'delivered' price for

LNG delivered to a ship's storage tanks. The availability and infrastructure for LNG marine bunkering is under development in North America, but the general availability is an important consideration.

The investment cost (CAPEX) for an LNG fuelled ship will be higher than a ship operating only on diesel fuel, and the space required for LNG storage tank(s) will for some vessels reduce the cargo capacity.

An LNG fuelled ship might choose to operate continuously on gas or only switch to gas when operating inside an ECA and this decision will involve a number of technical, economical, operational and regulatory issues. After 2016, a newly built dual fuelled vessel operating in NA ECA will need to operate solely on gas mode if not fitted with NO_x abatement systems. Switching to the diesel mode will be considered only in an emergency situation such as gas supply disruption.

Since methane is an aggressive Green House Gas (GHG), concerns in regards to the overall GHG emissions in the LNG supply chain, including the amount of methane released during the production, transport, processing, delivery and combustion of natural gas (GHG) is under increased scrutiny. These life cycle assessments, or 'well' to the 'propeller' analysis, have been done/and more studies are expected.[2,3]

3.3.3 Abatement technologies – Exhaust Gas Treatment Systems

The third option for a ship to comply with the regulatory limits on exhaust emissions from ships is the installation and use of exhaust gas treatment system. This option differs from the other options since the harmful substances are removed from the exhaust gas following the combustion process.

Exhaust gas treatment systems have been in common use within many other industries and the basic technology is mature; however, the use and adoption of these systems on board ships is a relatively new development and poses some additional challenges.

The exhaust gas treatment systems can be divided into SO_x scrubbers and NO_x reducing systems. SO_x scrubbers for marine use can either be classified as wet scrubbers that use water as the cleaning medium, or dry scrubbers that use a dry chemical. Wet systems are further divided into open loop, closed loop or hybrid system (open/closed).

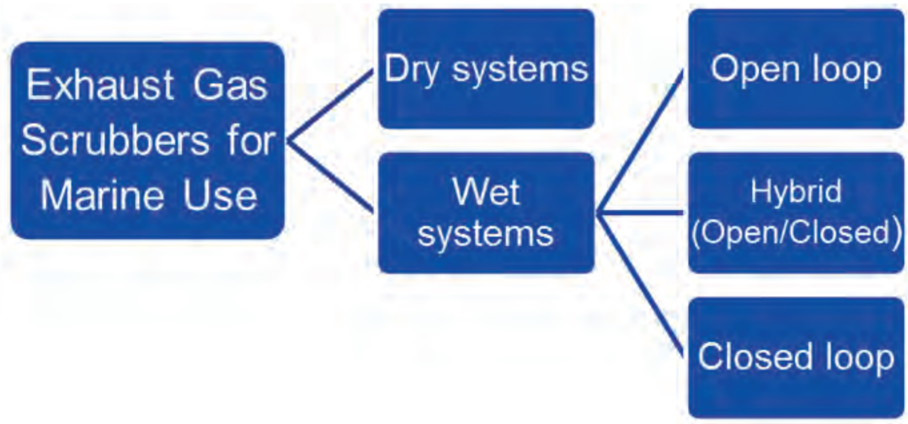


Figure 28: *Exhaust gas scrubbers classification*

NO_x reduction systems are either selective catalytic reduction (SCR), or exhaust gas recirculation (EGR).

The classification of EGR as a true exhaust gas treatment system is not correct since it can be considered as an on-engine technology and a method of primary NO_x control by reducing the combustion temperature. However, some EGR systems might also include scrubber system to remove SO_x.

3.4 Evaluation of compliance options

As discussed, in order to comply with the existing and future emission regulations and restrictions inside and outside the ECA, the following options are available based on existing technology and economic consideration.

1. Use of low sulphur diesel fuel
2. Use of alternative fuels
3. Use of abatement technologies, typically exhaust gas treatment system

The compliance strategy chosen for a vessel will depend on a number of factors, including if it is for an existing ship in operation or a new ship.

Some of the main issues that need to be considered in a strategy decision are listed below.

a. Ship power and fuel consumption amounts

b. OPEX/CAPEX of compliance options

c. Operation time in ECA

d. Space and location constraints on board

e. Loss of cargo space

f. Type of trade (fixed routes, schedule)

g. Fuel cost sensitivity

Table 15 lists some of the technical considerations and the issues to be evaluated for comparing the alternatives.

Table 15 – *Comparison of compliance alternatives*

Option	Pros	Cons	Issues/questions
Low Sulphur diesel	– Simple, technical mature, low CAPEX – Reduce SO_x and PM – Global availability – Competence is proven	– Expensive fuel – Issues with fuel switch – IMO Tier III after 2016 need SCR or EGR	– Global availability – Fuel quality – Future higher prices?
HFO + Scrubber	– Low cost fuel (HFO) – Lower CAPEX than LNG – Easier conversions – Process is mature – Global availability	– Space req. installation – Waste disposal, consumables (closed/hybrid) – Maintenance, complexity – IMO Tier III after 2016 need SCR or EGR	– Flag approval – Reliability/corrosion – Load dependence – Compatibility with SCR redundancy
LNG	– Low cost of natural gas – technical mature – Reduce SO_x, PM, NO_x, CO_2 – Favourable CAPEX for smaller vessel than scrubber – Environmental profile	– Engine, tank and system costs – Space for LNG tank – Range on gas could be limited – Lack of LNG bunkering infrastructure – Risk and safety challenges – IMO, international and national regulations are in progress	– Flag approval – LNG pricing – Global LNG bunker availability – LNG fuel quality standards – GHG (methane slip/emissions)

It is seen that using LNG as a fuel provides the greatest environmental benefits with respect to the reduction of SO_x, PM, NO_x and CO_2 emissions, but the fleetwide adoption of LNG as a fuel will depend on the availability, financial considerations and clear regulatory guidance.

4
Potential for LNG fuelled ships

Based on the information and discussions in chapters 2 and 3, this section will discuss the most likely ship segments that will adopt LNG as a fuel, as well as which ports and trading areas in North America which are expected to see the largest growth of LNG fuelled ships. Given the environmental and expected economic benefits of using LNG as a fuel , the long term potential for LNG use as a ship fuel is very promising; however, in the near future, the vessels and operations where the benefits are most significant will be the early adopters. This is already evident from the announced projects for LNG fuelled ships in North America, and these projects are initiating the development of the infrastructure and will also further drive the development of regulations needed for safe implementation of LNG as a marine fuel.

4.1 Profile of an LNG fuelled vessel

In order to assess the likelihood of LNG fuel use, the appproach is to identify the characteristics of a potential vessel. Since the cost of a conversion is quite high, due to the extensive modifications to the engine room and the addition of cryogenic tanks, the majority of LNG fuelled vessels are expected to be new builds with a smaller amount coming from conversions.

The vessels that are expected to use LNG as a fuel will have a combination of the following criteria.

1. Vessels that operate mostly inside the ECA, e.g. short sea shipping
2. Coastwise and regionally bound vessels, e.g. ferries, tugs, offshore vessels
3. Fuel cost sensitivity
4. Sufficient size and onboard space to accommodate the installation
5. LNG bunker availability and cost
6. Possibilities for conversion
7. Fleet renewal demand
8. Liner service, vessel on fixed routes
9. Environmental profile is beneficial

Vessels that operate mostly inside the ECA, e.g. short sea shipping

Until 2020 the ships that will have to operate under the strictest environmental regulations will be those that operate in an ECA. For these vessels the economic benefits are typically expected to be significant, and this is evident from cost analysis performed by DNV and in others studies.[4] The financial analysis is highly dependent on vessel type and cost assumptions, but for vessels which are operating more than 30% to 40% inside the ECA, the payback period of the increased CAPEX is financially attractive. Vessel types and ship segments in this category are the tankers, general cargo, container/ro-ro and cruise vessels with significant operations inside the ECA.

Coastwise and regionally bound vessels, e.g. ferries, tugs, offshore

These are vessels that are expected to only operate inside the ECA, often in a fixed region or inside a port, e.g. tugs, ATB/ITBs, ferries, lakers and offshore vessels. Since the vessels are typically smaller than short sea vessels, the increased CAPEX with LNG fuel can have more impact on the financial analysis.

Fuel cost sensitivity

If the fuel cost of the vessel is high relative to the other operation costs and the CAPEX, then the savings in fuel costs can more quickly offset the increased capital cost of the LNG installation. However, some ship segments where the charterers are responsible for the cost of fuel, the ship owner might have fewer financial incentives for building LNG fuelled ships.

Sufficient size to accommodate the installation

This is an important criterion due to the regulations governing gas fuelled ships with regards to the location of the LNG tank(s). Additionally, the vessel must have sufficient size to accommodate the increased volume of the fuel tanks. This is about 1.8 times the volume of the diesel tanks. Using an IMO type C independent tank installed with proper clearances, this can be 3 to 4 times the volume of an equivalent diesel tank. This increase in fuel tank volumes comes at the expense of cargo volume, and the vessel needs sufficient size to absorb the loss of cargo space.

LNG bunker availability and cost

An important consideration is the availability of LNG bunkering at the ports where the vessel is trading. For international shipping, in addition to the availability, the price difference between ports and regions are a consideration, e.g. the price of LNG in Europe or Asia versus the price in North America. Differences in bunkering methods and regulations need also to be evaluated. These considerations could appy to container vessels, tankers, car carriers and bulk carriers which operate on international routes in and out of the North American ECA.

Possibilities for conversion

Some vessels and segments have possibilities for converting to the use of LNG as a fuel. Espcially in USA, due to the relatively high cost of new building at a US shipyard, conversion might be a relevant option. This is already occurring, as seen in the conversion projects announced by Interlake Shipping Co., Washington State Ferries and TOTE, which were discussed in Chapter 2.

Fleet renewal demand

Certain segments in North America are expected to have a higher growth and demand for new vessels. It is expected that OSVs, oil/product tankers and smaller container/ro-ro vessels are segments that will see growth in North America and that many of the new builds will use LNG as a fuel.

Liner service

There are many different trading patterns and contractual arrangements for merchant ships, but in the near term, when LNG bunkering facilities are not widely available, ships on a liner type service will be better able to utilize LNG as a fuel. Liner service means that the vessel is trading between a few set ports on a regular schedule. This is in opposition to the ‘spot’ market, where a vessel will take a cargo from any port to any port. Depending on the industry segment, the percentage of ships on a liner type service and operating on the spot market can vary widely. For instance, about 50% of the international oil tanker fleet operates on the spot market, but nearly all container ships are on set routes.

Environmental profile is beneficial

As greater importance is placed on environmentally sustainable operations for businesses, LNG will become a more attractive fuel. Some industry segments value this green image more than others. It is expected that the cruise and passenger vessels, if the technical and regulatory challenges can be overcome, will embrace this aspect of LNG fuel use. Other industry segments such as offshore supply vessels (OSV) will see value here if oil majors and charterers continue to place a premium on sustainability.

It can be ascertained that the types and numbers of the confirmed projects for LNG fuelled ships in North America, as discussed in chapter 2, follow closely many of the defined criteria. It is also evident that in North America, the decision of using LNG as a fuel is mostly based on the financial attractiveness of the option. Therefore, the vessel types that are on order are often ocean going cargo vessels, which is different than most of the existing LNG fuelled ships in Northern Europe, and the development in North America could be an enabler for more use of LNG as a fuel also for international shipping.

4.2 LNG as fuel in North American regions

The analysis of the trading patterns and ship activity is also an indication of the ports and regions within the North American ECA that will have the highest potential and benefits for the LNG fuelled shipping and the development of LNG bunkering infrastructure. The Gulf of Mexico region, the Pacific Northwest, the Great Lakes and the Eastern seaboard are the areas with the highest international and domestic shipping activity.

The Gulf of Mexico is the busiest shipping region in North America and vessels of all types and sizes are trading in this area. The availability of LNG infrastructure and bunkering facilities in this region are in progress, and this will be further discussed in Chapter 5. The proximity to oil and gas production, both offshore and onshore, is a further enabler in the development and acceptance of LNG infrastructure and the operation of LNG fuelled ships. The first LNG fuelled vessel in North America, the Harvey Gulf OSVs, is expected to enter service in 2014. Being adjacent to the Wider Caribbean ECA, that comes into effect 1 January 2014, is an additional driver for LNG fuelled shipping in this region.

The Pacific Northwest shipping area, which includes both US and Canadian waters, is also a region where there is high shipping activity, both coastal and international shipping. This region has an extensive ferry network (WSF, BC Ferries, AMHS), large container ports, bulk terminals and tanker traffic. Port of Metro Vancouver is the largest Canadian port and is the fourth largest port in North America by tonnage. It is also a region where the environmental issues are important to the public and policymakers. As discussed in Chapter 2, TOTE Inc. will operate two LNG fuelled ro-ro ships between the Pacific Northwest and Alaska. Additionally, both WSF and BC Ferries intend to use LNG as a fuel for their ferry vessels. The development of the LNG infrastructure is planned both in US and Canada, and the West Coast Marine Liquefied Natural Gas (LNG) Supply Chain Joint Industry Project have investigated the feasibility of LNG fuelled shipping and the supplychain in more detail.[4]

The Great Lakes and the St Lawrence seaway is another area where the interest in the use of LNG as fuel is very high. The trading pattern and size of the Great Lakes cargo vessels are well suited for the use of LNG and these vessels will only operate inside the ECA. The conversion option is also expected to be a viable practical and economical option for these vessels, which is evident from the announced plans from Interlake Steamship Co.

The Eastern Seaboard of the US and Canada is also an area of high shipping activity, both for vessel calls from outside the ECA as well as for domestic ship traffic. The population and industrial density in this region is the highest in North America, and the proximity to the major transporation arteries, including highway, rail and inland waterways, is expected to facilate the multi-modal use of LNG as a transportaion fuel. The increased use of LNG as a fuel in this region will have a large impact, both environmentally and economically, and this will enable the development and demand of LNG fuelled shipping and infrastructure.

The majority of domestic waterborne transportation in the US are on the inland waterways using tugs and barges. The adoption of widespread use of LNG as a fuel for these vessels in the near future is uncertain, both from a technical, regulatory and economical consideration. However, as the infrastructure develops and the LNG fuel option becomes financially and operationally attractive, the market will drive technical innovations and challenge the regulatory stakeholders, including flag States and class societies.

5
LNG infrastructure and supply chain

The supply and demand of LNG is expected to grow significantly in the coming years. It is expected that globally there will be sufficient supply to the traditional LNG market. The demand for LNG to the marine market is not expected to be so high that it would influence the global supply based on the projection in the DNV Shipping 2020 study[8] and other studies. Figure 29 shows a projection of the global LNG supply and demand from a study from Galway Analysis.[9]

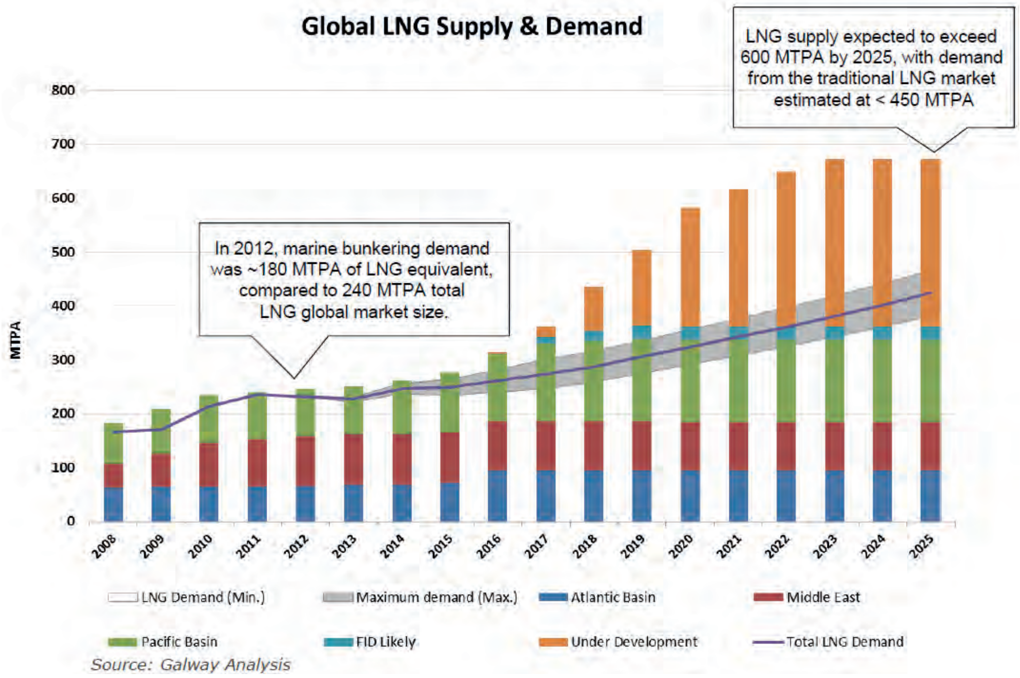


Figure 29: *Global LNG supply & demand*

However, in order to have a secure and stable supply of LNG as a fuel for ship, the appropriate bunkering methods and facilities must be in place, as well as the LNG infrastructure to ensure availability at the major ports and transportation hubs.

5.1 LNG bunkering options

The following are the three main options for bunkering an LNG fuelled ship.

1. Supply from a tank truck – Truck to Ship transfer (TTS)
2. Supply from a bunker vessel – Ship to Ship (STS)
3. Supply by shore tank and pipeline – Shore Tank to Ship (TPS)

The principles of these three options are shown in figure 30.

Figure 30: *Ship bunkering options*

In addition to these bunkering options, the use of standardized containers is also considered as a supply of LNG. These containers can be delivered directly to the ship. An example of such a container is shown in figure 31.

Figure 31: *Tank container for LNG*

The choice of bunkering options will depend on the regulatory framework, local conditions, cost and operational considerations. The type of vessel and the size of the onboard fuel tank will to a great extent influence the bunkering method and the required transfer rate. Typically, based on the LNG tank size and vessel type, the following are the likely preferred or practical bunkering methods.

Vessel type	LNG Tank Size (m^3)	Bunkering Method
Workboat, Tug	ITB > 100	TTS, Container
Ferries	100 – 200	TTS
OSV	> 300	TPS, TTS
Ships	500 – 10,000+	STS

TTS is often the early phase adoption and for vessels with small tank capacities such as ferries, tugs and coastal vessels. The most efficient is considered to be STS.

5.2 LNG supply chain

There are a number of possible ways of bringing the natural gas from the production well to the tanks on board a vessel in the form of LNG. A whitepaper from ICCT[10] identified eight pathways of bringing LNG to a bunkering facility and figure 32 is taken from their report.

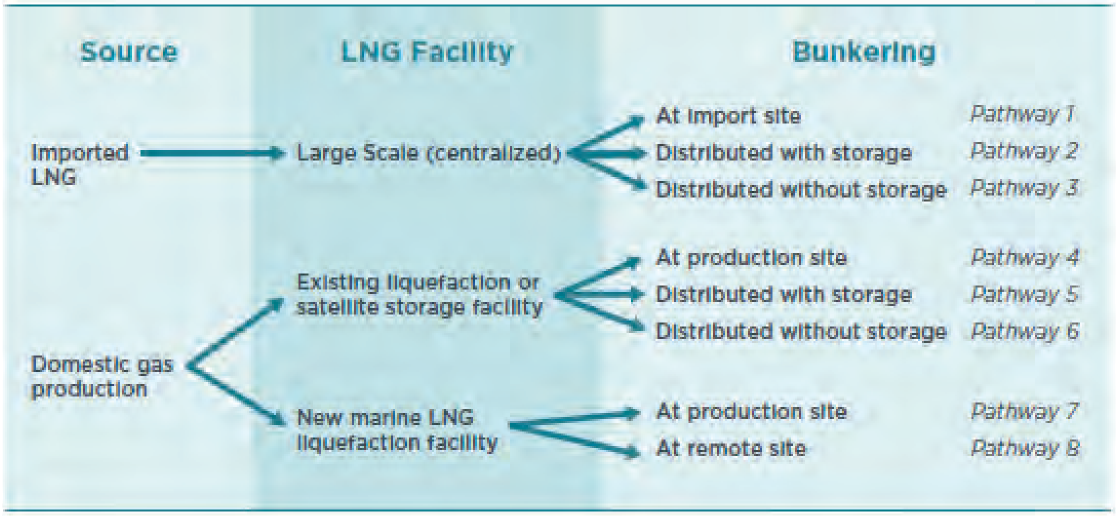


Figure 32: *LNG pathways*[10]

The pathways are differentiated by the source, the type of LNG facility, and the bunkering location and method. In North America, Pathways 4 to 8 would be considered most likely, as the source of the gas is expected to come from the onshore shale gas production. In order to further illustrate the possible pathways, figure 33 shows a graphic representation of the pathway.

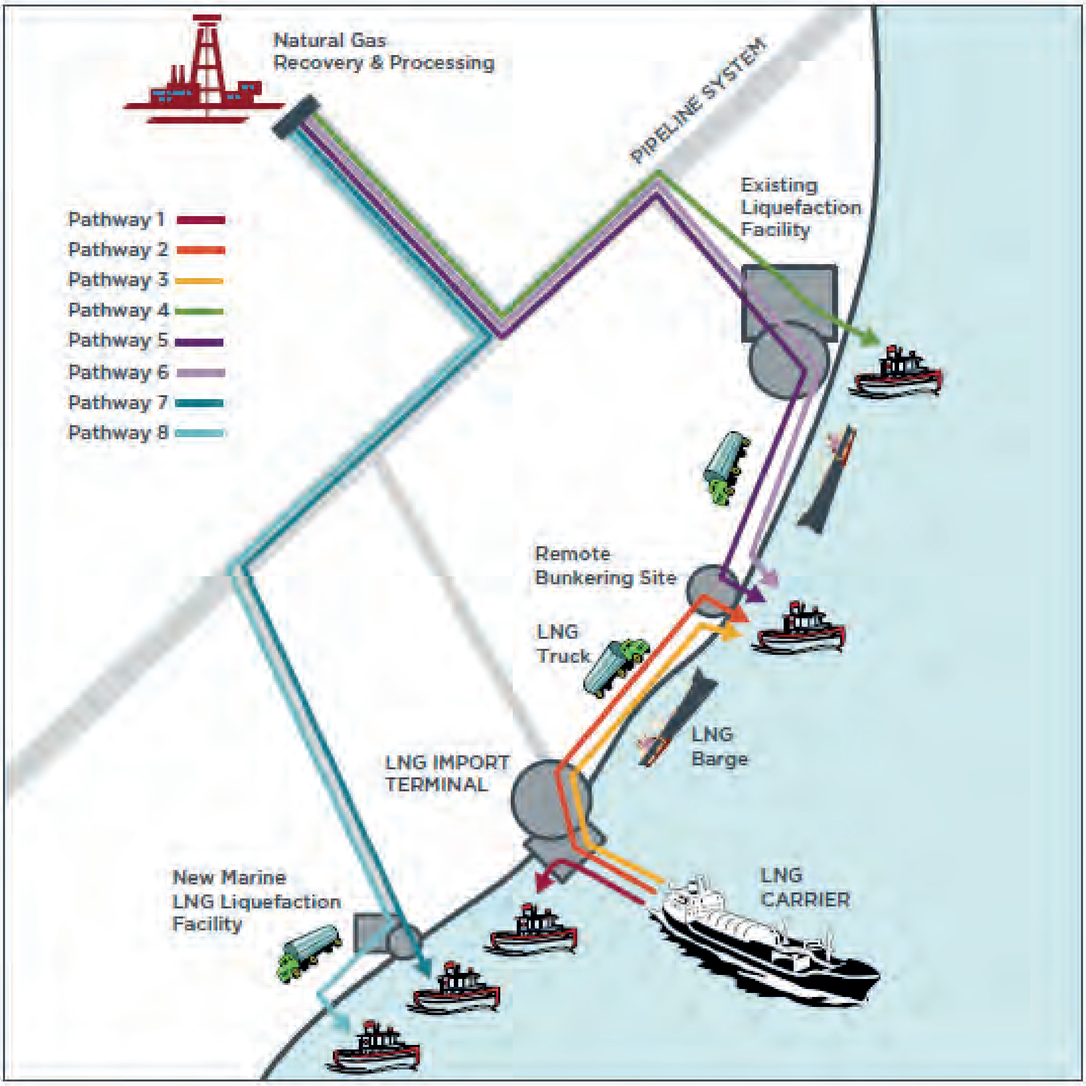


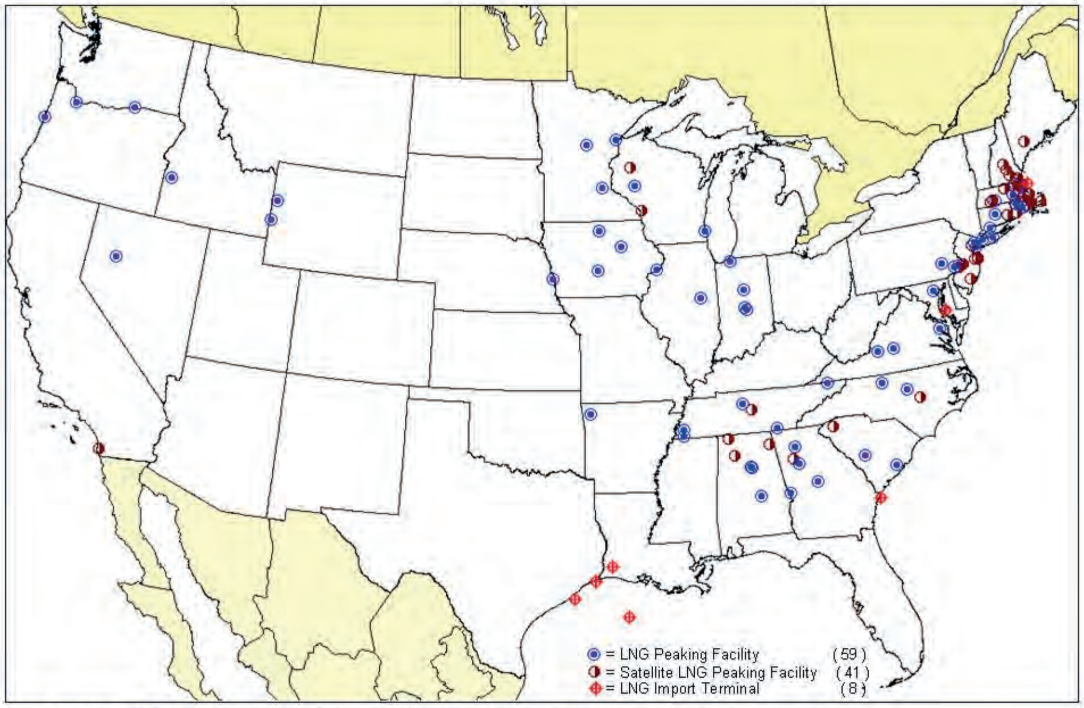
Figure 33: *Illustration of LNG pathways*[10]

In North America, the existing liquefaction facilities used for Pathways 4 to 6 could also include the planned LNG export terminals in the US. For Pathway 4, the bunkering facility is located at the liquefaction facility, and for Pathways 5 and 6, LNG is loaded on a truck or fuel barge and transported to a remote bunkering facility. Pathway 6 also includes LNG storage at the bunkering facility. Pathways 7 and 8 will use a dedicated small scale liquefaction facility with storage and bunkering that can either be done on site or remotely.

5.3 LNG availability in North America

Natural gas is widely available in USA and Canada; however, the availability of natural gas stored as LNG is only available in certain locations.

In USA, most of these facilities are so-called peak shaving plants, and are typically owned and operated by public energy utilities and energy producers. The purpose is to store natural gas as LNG for use during peak demand periods, and the plants will gasify the LNG and send it to the consumers via pipelines. There are about 100 peak shavers and about 50 with liquefaction facilities. Typically, the peak shavers have first obligation for supplying natural gas to the State or local utilities. In addition to the peaking facilities, there are a number of existing LNG import terminals in the US. However, the import of LNG to the US have declined in the last few years and according to the data from the US Energy Information Agency (EIA) the average daily deliveries from US LNG terminals from 1 January 2013 to 31 August 2013 averaged 0.3 Bcf/d, down about 40% from a comparable period in 2012. LNG imports through US terminals peaked in 2007 at over 2.1 Bcf/d. The figure shows the LNG facilities in the USA. There is one LNG export facility located in Kenai, Alaska, but this facility has been idle since 2012. Figure 34 shows the LNG facilities in the US (US EIA).



Note: Satellite LNG facilities have no liquefaction facilities. All supplies are transported to the site via tanker truck.
Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division Gas, Gas Transportation Information System, December 2008.

Figure 34: *US LNG facilities (2008)*

Because of the increased natural gas production from shale deposits in North America, some of the existing LNG import facilities are planned for conversions to LNG export facilities. This will typically require the addition of large scale liquefaction plants at the facility.

In addition, there are also a number of new LNG export facilities that are being planned. All of these facilities will have to apply to the US Department of Energy for export licence. An updated list of the proposed facilities can be found at the DOE website at:

http://energy.gov/sites/prod/files/2013/10/f4/Summary%20of%20LNG%20Application.pdf

As of 15 October 2013, four of the large planned export terminals have been approved for exporting LNG to countries that have a Free Trade Agreement (FTA) with USA, as well as exporting LNG to non-FTA countries.

Those facilities are as follows.

Company	Location	Quantity [Bcf/d]	Planned in service
Sabine Pass Liquefaction, LLC	Sabine Pass, LA	2.2	4Q 2015
Freeport LNG expansion LLC	Freeport, TX	1.4	2018+
Lake Charles Exports, LLC	Lake Charles, LA	2.0	2018
Dominion Cove Point LNG, LP	Baltimore, MD	1.77	2017

Canada is the world's third largest producer of natural gas and Canada has ample reserves for future production. A large portion of the gas production in Canada is exported by pipelines to the USA. In Canada, there are four LNG peak shaving plants and they are located as follows.[4]

Location	Ownership
Montreal, QC	GazMetro
Hagar, ON	Union Gas
Tilbury, BC	FortisBC
Mt. Hayes, BC	FortisBC

There is only one LNG import terminal in Canada, which is the Canaport LNG terminal in Saint John, New Brunswick and this plant receives gas from the offshore production.

There are also some gas export projects at various stages of development in Canada, and most of them are on the Canadian West Coast. These will primarily focus on exporting LNG to markets in Asia. As in the USA, each of the proposed projects needs to undergo various regulatory review processes to meet both local and federal requirements and the final investment decisions to proceed depends on having the major regulatory approvals in place and securing contracts with prospective buyers. More detail and locations of four of the projects are listed below.[4]

Project	Location	Quantity (Bcf/d)	Planned in service
Douglas Channel LNG	Kitimat, BC	0.09	2015
Kitimat LNG	Kitimat, BC	0.75	2018
LNG Canada	Kitimat, BC	5.0	n/a
Pacific Northwest LNG	Kitimat, BC	2.4	n/a

A map from the US Federal Energy Regulatory Commission (FERC) of proposed LNG Export terminals in North America as 12 November 2013 is shown in figure 35.

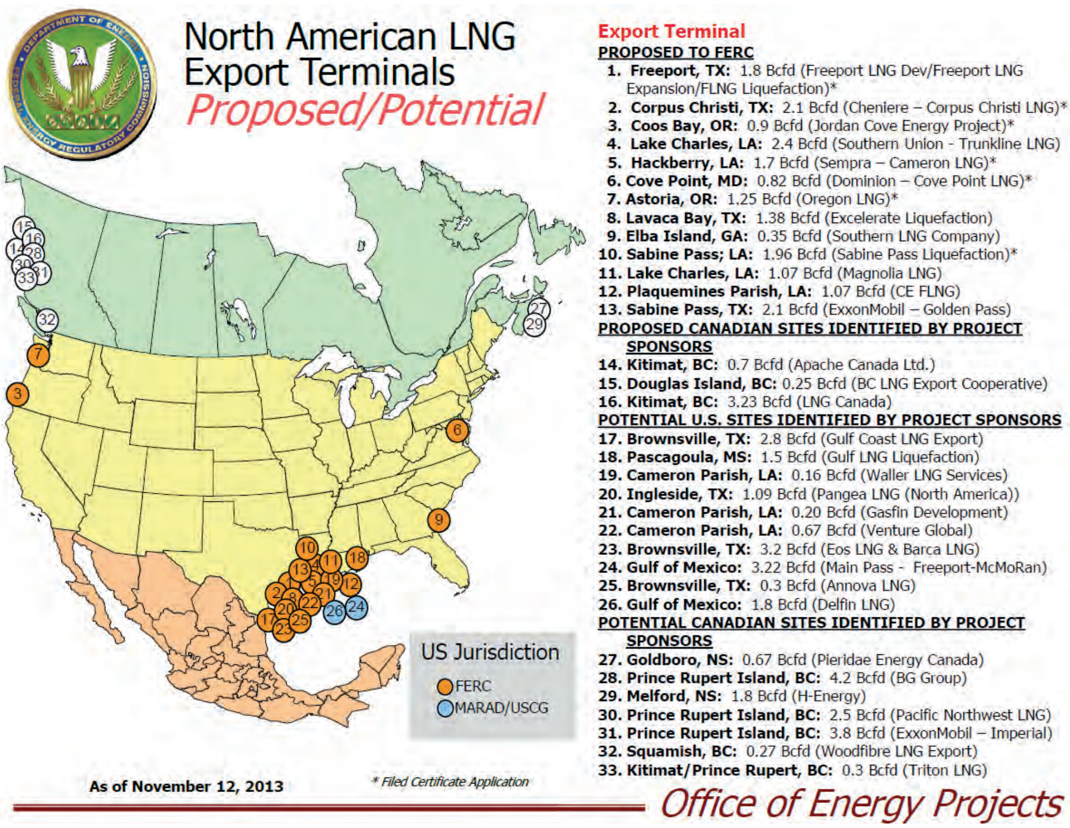


Figure 35: *NA Planned LNG export facilities*

There may be potential for the domestic LNG markets to be supplied by these facilities, and some of the smaller scale liquefaction projects have intentions to supply LNG as a fuel for ships. This study has not attempted to assess the probability of any specific project's successful implementation.

In the short term future the LNG needed for ship bunkering will likely come from the existing peak shaving plants and in the longer terms from dedicated small scale liquefaction plants for the domestic market. There are also plans to build berth side floating LNG liquefaction plants for export.

5.4 Existing and planned LNG bunkering infrastructure

Because of the large interest in the use of LNG as fuel in the transportation sector, including waterborne transportation, a number of projects for supplying LNG and supporting the infrastructure have been made public and new plans are being announced almost daily. Therefore, this report will provide a snapshot of the projects known at the time this report was written (November 2013), but since the market is in continuous development, the need to have updated information is recommended.

The North American market is also unique since a lot of interest of using LNG as a fuel also comes from the heavy-duty trucks, fleet operators, mining, oil and gas, and the railway industry. The development of multi-modal LNG facilities and infrastructure, which might serve more than one mode of use, could be a key element in building an LNG infrastructure.

5.4.1 Existing LNG bunkering facilities

As of November 2013, there are no existing marine bunkering facilities in North America. There is a growing network of LNG fuelling stations dedicated to supplying LNG to road vehicles. According to the website maintained by the US DOE Alternative Fuels Data Center, there are 42 existing retail LNG fuelling stations in the US to serve LNG fuelled vehicles.

5.4.2 Planned LNG bunkering facilities

There are several projects in various stages of development to deliver LNG to the transportation sector, including LNG for marine use. Some of these projects will primarily support some of the specific confirmed LNG fuelled vessels to enter service in North America, other projects plan to supply the expected general increase in demand for LNG as a ship fuel, as well as supplying LNG for multi-modal use.

The list of projects with most relevance to the marine market is below.

No.	Project	Location	Type*	Capacity (mmTPA)	Date
1	Harvey Gulf	Port Fourchon, LA	A	–	1Q- 2014
2	Shell LNG	Geismar, LA	B	0.25	2016
3	Shell LNG	Sarnia, ON [CAN]	B	0.25	2016
4	GazMetro	Quebec [CAN]	A	–	2014
5	Eagle LNG	Jacksonville, FL	B	0.19	2016
6	Eagle LNG	Tacoma, WA	B	0.19	2016+
7	LNG America	US Gulf Coast	B	0.3	–
8	Waller Marine	US Gulf Coast	B	0.3	–

* A: Storage facility and bunkering
B: Liquefaction and storage

Project 1

The bunkering facility will be designed to support operations of Harvey Gulf's series of LNG fuelled offshore supply vessels (OSVs).

The facility will consist of two sites each having 270,000 gallons of LNG storage capacity and the ability to transfer 500 gallons per minute. The facility will also be capable of supporting over-the-road vehicles that operate on LNG. The estimate to complete the first site is February 2014, with the second site following shortly thereafter.

Projects 2 and 3

Shell plans to install a small-scale liquefaction plant in Geismar, Louisiana, to supply LNG along the Mississippi River, the Intra-Coastal Waterway and to the offshore Gulf of Mexico and the onshore oil and gas exploration areas of Texas and Louisiana. Shell has a memorandum of understanding with Edison Chouest Offshore companies (ECO) to supply LNG fuel to marine vessels that operate in the Gulf of Mexico and to provide what is anticipated to be the first LNG barging and bunkering operation in North America at Port Fourchon, Louisiana. The LNG transport barges will move the fuel from the Geismar production site to Port Fourchon where it will be bunkered into customer vessels. The ship bunkering is planned to done by bunker vessel/barge or tanker trucks.

A similar small-scale liquefaction plant will be installed in Sarnia, Ontario to supply LNG fuel to all five Great Lakes, their bordering US states and Canadian provinces and the St Lawrence Seaway. The Interlake Steamship Company is expected to be the first marine customer in this region, as it begins the conversion of its vessels.

Project 4

Gaz Métro will supply the three new ferries for Société des traversiers du Québec (STQ) with LNG. The company also has plans to develop a larger LNG infrastructure network in Canada.

Projects 5 and 6

Eagle Energy Partners is a consortium between Clean Energy Fuels Corp, Ferus Natural Gas Fuels and General Electric. They plan to develop regional LNG projects to meet the growing demand in industries such as long-haul trucking, rail, mining, marine and oil and gas services.

The goal of the consortium is to build out LNG infrastructure throughout the North America, starting with the locations in Jacksonville, Florida and Tacoma, Washington. The facilities will include small-scale liquefaction plants and focus on delivery of LNG to ships, rail and long-haul transport trucks.

The two plants will each have a production capacity of 300,000 gallons/day and is expected to cost $100 million each. Smaller, 100,000 gallon/day plants are to be built in Ohio, Colorado, Texas and possibly in Canada, at a typical cost of $45 million each. Each plant will also require about $10 million to buy specialized LNG delivery trucks and storage tanks to handle and distribute the fuel.

Project 7

LNG America intends to obtain LNG from Cheniere Energy's large-scale Sabine Pass LNG export facility currently under construction in Cameron Parish, Louisiana. LNG America will own and operate logistics infrastructure necessary to deliver LNG to marine and on-shore customers. The company envision the use of LNG bunker vessels, tanker trucks, storage and loading facilities to deliver LNG. The initial geographic focus for LNG America is on the US Gulf Coast with plans to expand into other regions as the markets develop.

Project 8

Waller Marine, Inc., through its LNG development subsidiaries, Waller Energy Holdings, LLC and Waller LNG Services, LLC, intends to build a liquefaction facility in southwest Louisiana. Using small-scale liquefaction technology, the plan is to install nominal 500,000 gallon per day LNG trains in phases as the market and demand for marine LNG expands.

To enable the supply and distribution of LNG to and from small scale LNG terminals and for bunkering LNG as a marine fuel, Waller has designed a series of small LNG vessels ranging from its 2,000 to 10,000 cubic metre capacity river transport and bunker barges and its 10,000 to 30,000 cubic metre coastwise ATB LNG vessels.

5.4.3 LNG infrastructure Canadian West Coast

On the West Coast of Canada, there is some existing LNG production capacity which was developed with the primary purpose of acting as peak shaving plants for the local natural gas distribution company, FortisBC. Additional LNG infrastructure is being planned to support local demand for natural gas as a transportation fuel. Additional natural gas pipelines are planned from the gas production areas in Northwest British Columbia to liquefaction facilities in Prince Rubert, Kitimat, and the Vancouver area. The local gas utilities, FortisBC and PNG, plan to develop local distribution systems for LNG as the market grows and this also includes demand from the marine transportation sector. Teekay is a partner with FortisBC and have proposed to establish LNG bunkering in the Pacific Northwest, with at least one bunkering vessel, by 2016.

There are also pipelines between the Canada and the US on the West coast, which will facilitate the growth of LNG fuelled shipping in Pacific Northwest.

Ferus Natural Gas Fuels and ENN Canada Corporation have announced a joint venture to construct, own and operate an LNG liquefaction plant in Vancouver, British Columbia to service trucking market as well as other high-horsepower applications including marine, rail, mining, and oil and gas exploration. There will also be a plant in Edmonton, Alberta. Both facilities will initially be built to produce 100,000 US gallons per day of LNG, with the ability to expand as demand grows. Site selection will be determined within six months, and construction will be initiated immediately afterwards. First product is expected early in 2016.

5.4.4 Additional LNG infrastructure

In addition to the projects discussed in the previous section which focus on the delivery of LNG as a fuel to the marine market, there are also many plans for development of LNG infrastructure for the more general multi-modal use of LNG.

The US company AGL resources, which operates five peak shaving facilities and is currently the largest producer of LNG in the USA with a production capacity of 540,000 gallons of LNG per day, is planning to expand its facilities and create a network for distribution of LNG in the southeastern USA through its subsidiary Pivotal LNG. A summary of the company's five LNG production facilities and a map showing the locations is below in figure 36.

	Storage Bcf	Liquefaction Mcf/D	Required for Utility Ops Mcf/Yr	Theoretical Max Available Mcf/Yr	Theoretical Max Available Gals/Yr
CHATTANOOGA	1.2	10,000	923,223	2,426,777	29,372,644
MACON	1.5	10,000	1,003,809	2,346,191	28,397,263
CHEROKEE	2.0	10,000	1,101,169	2,248,831	27,218,860
RIVERDALE	2.5	10,000	1,674,019	1,675,981	20,285,333
TRUSSVILLE	0.4	5,000	-	1,675,000	20,273,463
Total	7.6	45,000	4,702,220	10,372,780	125,547,563

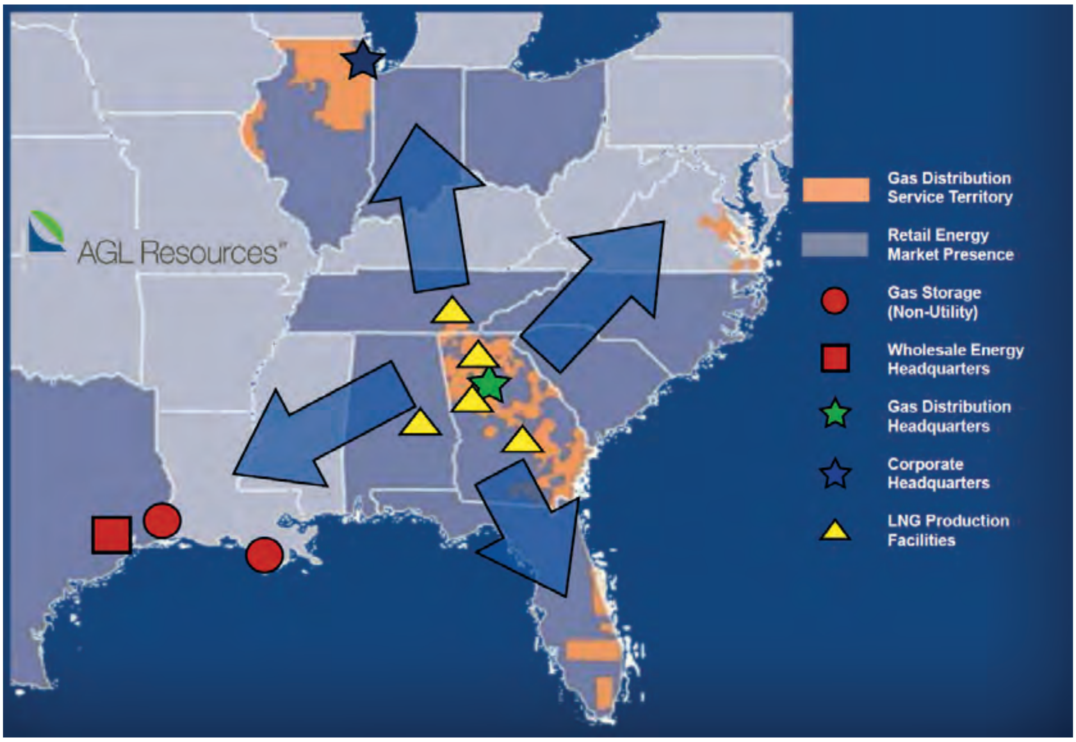


Figure 36: *AGLR LNG facilities*[11]

In another development, the transportation company UPS (United Parcel Service) have plans to significantly increase the number of LNG fuelled tractor-trailers the company use for highway shipping in the US. The company already operates about a 100 LNG large trucks, and intends to purchase another 700 by the end of 2014. This plan also includes the expansion of LNG fuelling stations and infrastructure across the USA.

5.5 Cost of LNG

The relatively low cost of natural gas when compared to diesel fuel is an important driver in the interest of using LNG as a fuel for shipping and this is particularly the case in North America. The current price of natural gas is different in North America, Europe and Asia. Figure 37 shows the prices in USD from February 2009 until December 2012 for the three main natural gas price indices, the Henry Hub (USA), NBP (Europe) and JKM (Japan/Korea). (Data from Platts & Professor Kenneth B Medlock III, Rice University).[12]

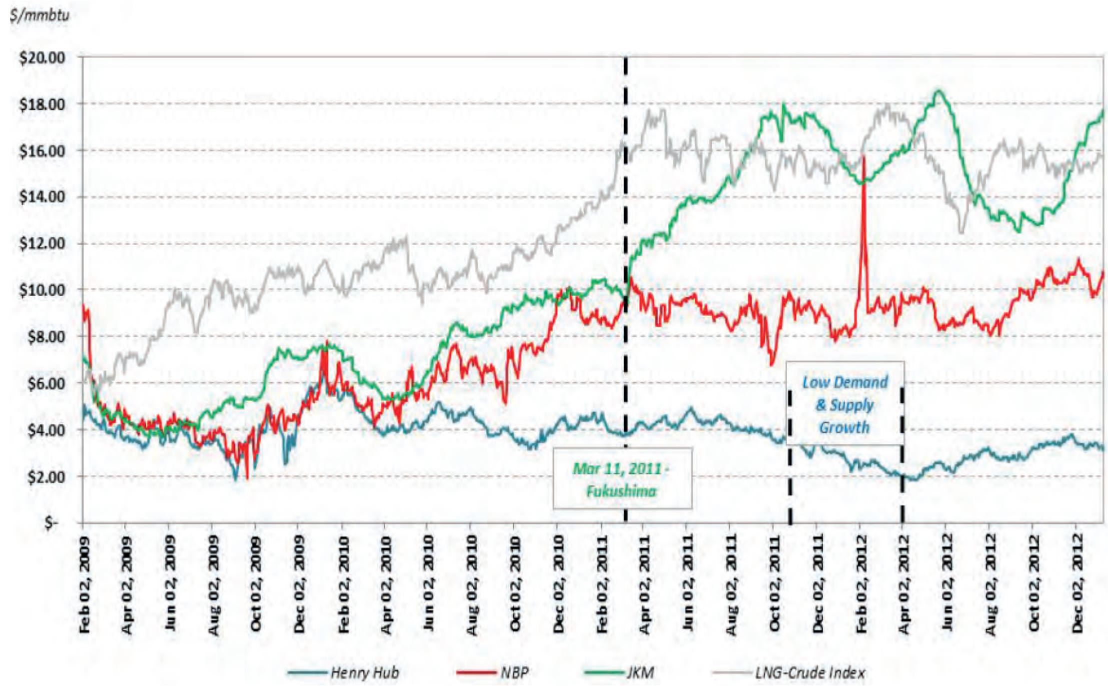


Figure 37: *Price history natural gas – world indices*

The price difference between the natural gas price and diesel prices is shown in figure 38.[13] The prices in both figure 38 and figure 37 are shown based on the energy content of the fuel, which is more relevant than the quantity.

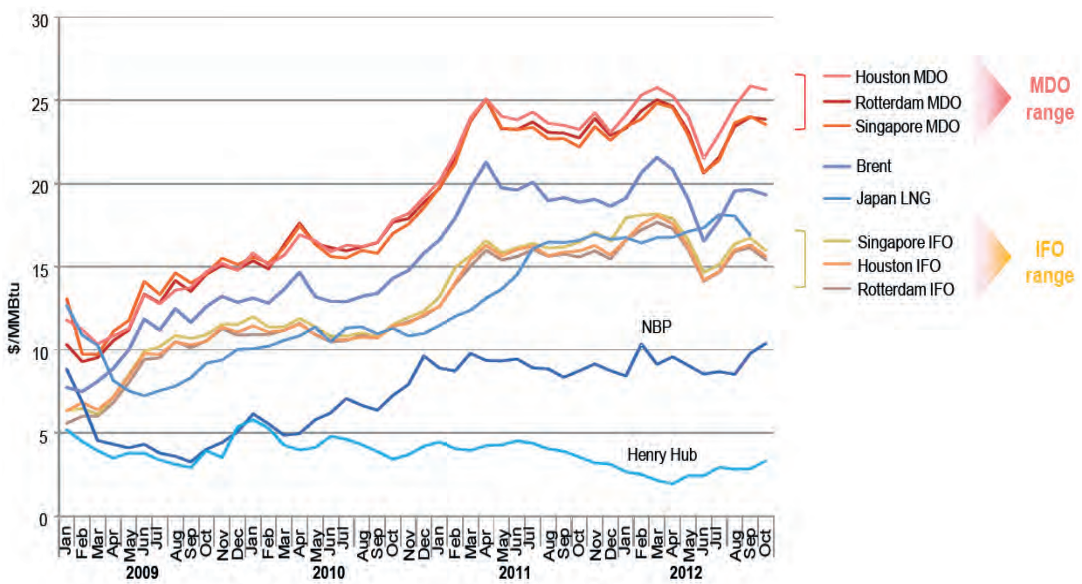


Figure 38: *Price history natural gas vs. marine diesel fuels*[12]

It is seen that since 2011, the Henry Hub (US) price range gas has been 3 to 4 USD/mmBTU, while the MDO/MGO price range 21 to 26 USD/mmBTU, and the IFO price range 15 to 18 USD/mmBTU. The bunker prices also show variations depending on the region and port. In November 2013, the average bunker prices in North America are shown in the table below, both in terms of quantity and energy content.

Americas	IFO380	IFO180	MDO/MGO
Average ($/ton)	$610	$680	$1,020
Average ($/mmBTU)	$15	$17	$25

However, the comparison of the fuel cost between marine diesel fuel and LNG must be based on the cost of the delivered fuel to the ships tanks (FOB). There are a number of variables that need to be analysed in order to estimate the LNG bunker price. The Henry Hub price is the cost of the feedstock gas, and all the costs and profit margins involved in transportation, processing, storage and bunkering must be included. The estimate of these costs will also depend on the supply chain or the pathway of LNG to the market. A number of possible pathways were described in section 5.2. For each of the participants in the supply-chain, the business case must make economic sense, and this also includes the final user.

There have been carried out estimates of the expected LNG bunker price in North America. The results are similar but there are also significant variations. The largest contributors to the LNG cost are the cost of liquefaction and the bunkering cost. Uncertainty in these two parameters will have the largest effect on the LNG bunker cost. The cost of liquefaction will depend on the capital costs (CAPEX) of the liquefaction plant, fixed and variable operating costs (OPEX), and the utilization rate of the plant capacity. Based on knowledge of these parameters, an analysis of the expected liquefaction cost can be carried out.

The bunkering cost will to a great extent depend on the pricing model and profit margin that is chosen by the bunker supplier.

An estimate of the LNG bunker price in North America is shown in table 16. The analysis is based on assumptions of the capital cost and the operating cost for a new small-scale liquefaction plant, as well as cost for transportation by pipeline and by trucks. It has assumed an add-on (profit margin) of $5, which is based on industry estimates.

Table 16 – *LNG price estimate*

Price Estimate for LNG Bunker		
Cost of gas: $/mmbtu (Henry Hub)	$4.00	mmBTU
Pipeline charge: 0.5	$0.50	mmBTU
Liquefaction Cost	$5.09	mmBTU
Trucking @ $7/load mile: 0.9	$0.90	mmBTU
Total at dock:	$10.49	mmBTU
Bunkering:	$5.00	mmBTU
Total at sea:	$15.49	mmBTU

The liquefaction cost is based on a new plant (CAPEX $50,000,000) and investment rate of return of 11% for ten years. Liquefaction capacity is 100,000 gallons per day, 80% availability.

The estimate is comparable with other recent studies[4] and the difference is mainly related to the uncertainty in the liquefaction cost. The pathway from the liquefaction plant to the ship will also influence the price depending on whether the bunkering is done shore-side from a storage tank, with a tanker truck, or with a bunker vessel.

It can be estimated that the LNG bunker price in the near future will be equal or less than the residual fuel price (IFO180/380) and about 60% less than the distillate (MDO/MGO) price. The future price projections are more uncertain, but the cost of low sulphur diesel fuel is expected to increase because of the increased demand, refinery cost and capacity. The delivered fuel price projections until 2035 from the US EIA is shown in figure 39. This is the baseline case assuming an annual economic growth of 2.5%.

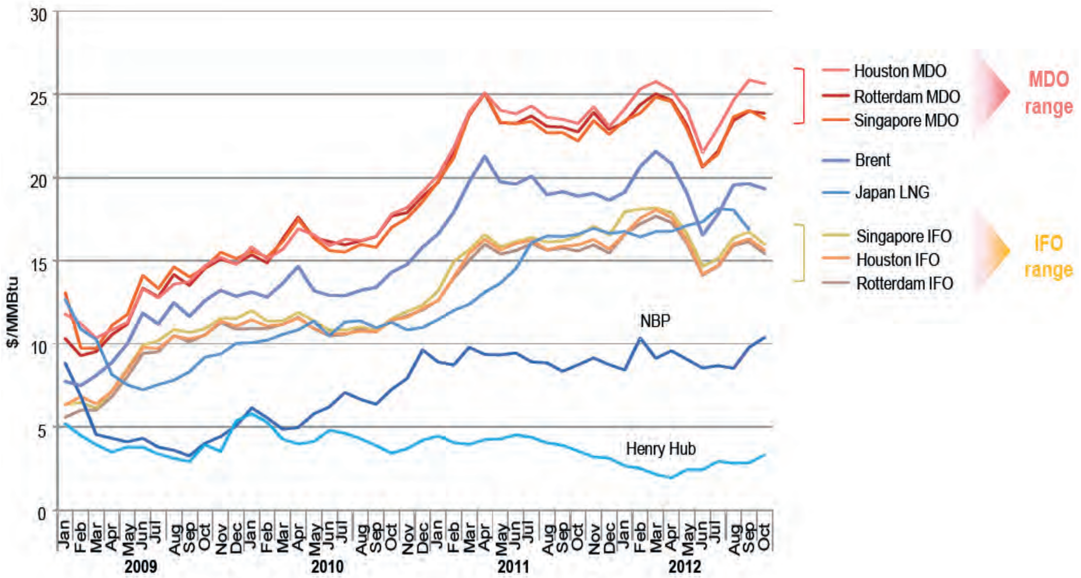


Figure 39: *US EIA fuel price projections to 2035*

It is predicted that the natural gas price in North America will continue to be low relative to the diesel fuel market. Even with the future potential for LNG export from North America, it is not considered that this will have a great impact on the domestic natural gas price. However, the LNG export market will be coupled to the worldwide LNG demand and this will influence the business decision for the operators of the large-scale LNG export facilities.

Another factor that will drive the cost of LNG available as a ship fuel is how the market will develop. One scenario is that the market will be dominated by one or only a very few suppliers. The pricing of LNG as a marine fuel might then be closer coupled to the marine diesel fuel pricing. Another scenario is that the market becomes more competitive, including the multi-modal use of LNG, and the market forces will create a more competitive environment.

6
Current regulatory regime

6.1 Overview

This chapter will provide an overview of the current regulatory regimes for LNG fuelled shipping. A complete regulatory framework should provide oversight and guidelines for the design, manufacturing, installation, personnel certification and operation of gas fuelled ships.

The purpose of the regulations is to address the risks and safety associated with the carriage, storage, handling, transfer, exposure, release and use of natural gas on board a ship.

The interface with shore-side activities including bunkering, security, personnel certification and maintenance will also be subject to regulatory oversight.

An appropriate regulatory framework will be one of the key enablers for the use of LNG as a ship fuel.

6.2 International regulations and guidelines

The current international regulations, codes and guidelines applicable to LNG as a fuel for shipping are developed by IMO, standard bodies (ISO, IEC, EN, etc.), classification societies and industry groups.

6.2.1 IMO

The most relevant IMO regulations applicable to the use of LNG as a fuel for shipping are:

- SOLAS convention including requirements for maritime fuels
- STCW convention including training requirements for crews
- International Code for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code, referenced within SOLAS Chapter VII, Part C) including requirements for the construction and operation of LNG tanker
- Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships MSC.285(86)
- International Code of Safety for Ships using Gases or other low Flashpoint Fuels (IGF Code, in development, will be referenced within SOLAS) including requirements for the construction and operation of gas-fuelled ships.

Based on IGC code, IMO recognizes the use of liquefied natural gas as ship's fuel in the special case of gas carrying ships, but historically did not explicitly allow LNG as fuel for other types of ship. However, the IGF Code under development will allow the use of gases or other low flashpoint fuels. The IGF Code will not be in place until 2014 (and will probably not be ratified for a further two years), but IMO issued Interim Guidelines (resolution MSC.285(86)) in 2009 with which the IGF Code will be consistent and which provide guidance until the code has been developed. The ships being built today are being built following the Interim Guidelines and the Classification Rules, but the acceptance of a gas fuelled ship and the Interim Guidelines is up to the flag State.

6.2.2 ISO (International Organization for Standardization)

The International Organization for Standardization (ISO) is a non-governmental organization and a network for national standard bodies developing standards for all kinds of industries on international level. The ISO is also involved in the development of standards for the shipping industries and closely works together with the IMO.

One important work by ISO related to the LNG supply chain is:

– *Guidelines for systems and installations for supply of LNG as fuel to ships* (currently under development in the ISO Technical Committee 67 WG) including requirements for safety, components and systems, and training.

The objectives of the document are defined as follows:

– Ensure safety to personnel (crew, bunkering operators and 3rd party personnel)

– Minimize/eliminate release of natural gas to the atmosphere

– Promote standardization in equipment (connectors and instrumentation) and procedures

– Give functional requirements to explain principles and allow for future improvements and developments by not prescribing existing solutions based on current and limited experience

– Allow for an effective review and permit process of simple and standardized solutions.

A draft version of this document was published as ISO/DTS 18683: *Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships, on 29 June 2013*.

Another document from ISO is the ISO 28460:2010 standard *Installation and Equipment for Liquefied Natural Gas – Ship to shore interface and Port*.

ISO 28460:2010 specifies the requirements for ship, terminal and port service providers to ensure the safe transit of an LNG carrier through the port area and the safe and efficient transfer of its cargo.

ISO 28460:2010 applies only to conventional onshore LNG terminals and to the handling of LNGCs in international trade.

6.2.3 Classification societies

DNV introduced the first set of Rules for Gas Fuelled ships in 2001 and these rules were used as input for the IMO Interim Guidelines issued in 2009, and since then most IACS members, including ABS, LR and NK have issued rules and guidelines related to the design and safety requirements for the gas fuelled ship and onboard systems.

In addition to the ship rules, classification societies are developing guidelines and standards related to the bunkering operation and personnel certification.

In April 2013, DNV issued a Standard for Certification No. 3.325, *Competence Related to the On Board Use of LNG as Fuel*. The scope of the standard is to identify a suggested minimum level of knowledge and skills for people in various roles on board a vessel using LNG as fuel.

DNV GL is developing a Recommended Practice (RP) for LNG bunkering. A draft was issued in October 2013, and following an external comment period, the document will be formally published.

6.2.4 Industry Groups and Associations

The Society of International Gas Tanker & Terminal Operators (SIGTTO) is a non-profit organization representing the liquefied gas carrier operators and terminal industries. The purpose of the SIGTTO is to promote shipping and terminal operations for liquefied gases which are safe, environmentally responsible and reliable. SIGTTO also publish guidelines and reports for development of best operating practices. The guidelines describe the handling and transport of large quantities of LNG as cargo, handled by an experienced crew on gas carriers and LNG terminals, and has formed the basis for the development of current guidelines for the bunkering of LNG as ship fuel.

Most important guidelines are:

– LNG Ship to Ship Transfer Guidelines including guidance for safety, communication, manoeuvring, mooring and equipment for vessels undertaking side-by-side ship to ship transfer;

– *Liquefied Gas Fire Hazard Management* including the principles of liquefied gas fire prevention and fire fighting

- *ESD Arrangements & linked ship/shore systems for liquefied gas carriers* including guidance for functional requirements and associated safety systems for ESD arrangements
- *Liquefied Gas Handling Principles on Ships and in Terminals* including guidance for the handling of LNG, LPG and chemical gases for serving ship's officers and terminal operational staff
- *LNG Operations in Port Areas* including an overview of risk related to LNG handling within port areas.

SIGTTO announced in May 2013 the formation of a new organization for gas fuelled vessels: Society for Gas as a Marine Fuel (SGMF). One of the purposes of SGMF will be to develop advice and guidance for best industrial practice among its members and to develop best practice for the use of LNG as marine fuel.

6.3 National and local regulations within North America

The feasibility of LNG as a ship fuel in North America will also depend on the national and local acceptance and awareness of both the benefits and risk involved in the use of natural gas as a ship fuel. The great majority of the public in USA and Canada are familiar with natural gas supplied by pipeline into their houses and used for domestic heating and cooking. The use of natural gas buses and other vehicles are also a common sight in many cities.

However, the use of LNG as a ship fuel is a new development and it is important that the domestic regulatory framework is in place to support the adoption of the expected increase in demand. Both in the US and Canada, the regulations pertaining to the LNG facilities and infrastructure is governed by different federal (national) jurisdictions and agencies, as well as local regulatory entities.

6.3.1 USA

The responsibility for the US flag and port state regulations for the design, construction and operation of LNG fuelled ships is with the US Coast Guard (USCG). The USCG also has regulatory oversight of the bunkering of LNG fuelled ships.

USCG has issued the policy letter CG-521 No. 01-12 Equivalency Determination – Design Criteria for Natural Gas Fuel Systems. It provides a basis for USCG to accept the design of gas fuelled ships, and is based on IMO resolution MSC.285 (86) with some modifications and additions. The main changes are related to:

- use of US standards for type approved products
- fire protection, including monitoring systems
- electrical systems, in particular the designation of hazardous areas.

The USCG does also require special approval for the use of LNG storage tanks below the accommodation area of a ship, as well as for the use of the ESD (Emergency Shut Down) concept for gas engines on board an LNG fuelled ship.

The policy letter does not explicitly address bunkering of gas fuelled ships or training or certification requirements for operating personnel. However, the USCG has a draft policy letter that addresses these issues:

- USCG Draft PL No. 01-13 Guidelines for Liquefied Gas Fuel Transfer Operations and Training of Personnel of Vessels using Natural Gas as Fuel.

In addition, the USCG has drafted a policy letter related to bunkering facilities and vessel bunker operations:

- USCG Draft PL No. 02-13 Guidance Related to Vessels and Waterfront facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations.

It is expected that the USCG will formally issue the policy letters to the public following an internal process.

The existing US federal regulations for LNG facilities regardless of the size are generally covered in the following codes and regulations.

Code	Description
NFPA59A	Standard for the Production, Storage and handling of LNG
USCG 33CFR Part 127	Waterfront facilities handling LNG and Liquefied Hazardous Gas
USCG 49CFR Part 193	LNG facilities: Federal Safety Standard
18 CFR Part 153	Applications for authorization to construct, operate or modify facilities used for the export or import of natural gas

The Code of Federal Regulations (CFR) is the codification of the general and permanent rules and regulations (sometimes called administrative law) published in the Federal Register by the executive departments and agencies of the federal government of the United States.

Other federal agencies that have regulations and responsibilities related to LNG facilities are:

- Department of Energy
- Federal Energy Regulatory Commission (FERC)
- Department of Transportation (DOT)
- US Environmental Protection Agency (EPA)
- US Minerals Management Service
- US Fish and Wildlife Service
- US Department of Labor Occupational Safety & Health Administration (OSHA)
- US Army Corps of Engineers.

There are also State and local agencies that might have oversight and regulations, including each State's Department of Environmental Protection and the local Fire Department (Fire Marshal).

6.3.2 Canada

In Canada, Transport Canada is the federal agency that regulates shipping in Canada, including the flag regulations for Canadian flagged vessels.

The Canada Shipping Act, 2001, applies to all Canadian flagged vessels and all vessels in Canadian waters except those belonging to the Canadian Forces, or foreign military. The Canadian regulations currently do not permit the use of LNG as fuel for ships and the IMO Interim Guidelines are not incorporated by reference in any Canadian regulation. However, there is work in progress in order to develop a regulatory framework to accepting the use of LNG as fuel for Canadian vessels. There is currently a process in place (MTRB – Marine Technical Review Board) which would allow for LNG vessels to visit Canadian ports.

There are currently no specific Canadian regulations applicable to the safety during LNG bunkering, but the TP 743E TERMPOL code (Technical Review Process of Marine Terminal Systems and Transshipment Sites) was established by Transport Canada in 1977 as a means of measuring the navigational risks associated with the location and operation of marine terminals for large oil tankers. The TERMPOL Code was expanded in 1982 to include, on a voluntary basis, proposals for marine terminals designed to handle bulk shipments of liquefied natural gas (LNG), liquefied petroleum gas (LPG) and chemicals. The future of TERMPOL is somewhat unclear, but it is expected that its principles will be preserved in ongoing codes.[4]

A Canadian Standards Association (CSA) code applicable to LNG facilities is:

CSA Z276-2011 *Liquefied natural gas (LNG) – Production, storage, and handling.*

The scope of CSA Z276-2011 explicitly excludes road, rail and marine fuelling applications. According to Reference,[4] it contains much material that can be applied to bunkering and CSA is in the process of adding an Annex (called Annex D) to the Standard to provide requirements for LNG Vehicle Fueling Stations. This Annex was approved at the September 2013 Z276 Technical Committee meeting and will be published as a supplement to Z276-2011 at the end of 2014. A Work Group is formed to review the scope of Z276 to consider inclusion of further transportation related facilities including those applicable to marine transport. The current edition of Z276 also contains Annex B - Guidelines for Small LNG Facilities. The current definition of 'small facility' in Z276: a shop-fabricated process plant that is tested as an assembled and functional plant prior to shipment. The maximum storage volume of a small facility is 265 m^3 (70 000 US gal) of liquid. Another Work Group has begun a review and update of Annex B and will also address inclusion of further transportation related requirements as they are identified and approved by the Technical Committee. The date of inclusion of future requirements in either a new edition of, or supplement to, Z276 is uncertain at this time.

The West Coast Marine Liquefied Natural Gas (LNG) Supply Chain Joint Industry Project[4] identified existing Canadian regulations applicable to LNG fuelled ships and will provide recommendations for the policy development of a Canadian regulatory framework with respect to design and construction of LNG ships, operation of LNG fuelled ships in Canadian Waterways and Ports, bunkering of LNG fuelled ships, and measures to prevent security incidents. It is generally proposed that the framework be based on reference to the international codes and guidelines that are in place or in development, and also use the existing Canadian processes and regulations, e.g. TERMPOL and MTRB.

7 Environmental benefits

The environmental benefits of using LNG as fuel are significant. Compared to the use of diesel fuel, use of LNG will reduce the NO_x emission by approximately 90% on a lean burn gas fuelled engine, and the SO_x and particle matters emissions are negligible without the need of any abatement technologies. The CO_2 emissions are about 20% lower compared to diesel fuel because of the lower carbon content. However, the overall effect on GHG (Green House Gas) emissions needs further study.

7.1 Existing environmental impact of shipping in NA ECA

Ships are significant contributors to the US and Canadian mobile-source emission inventories.

The ships generate significant emissions of fine particulate matter (PM2.5), NO_x and SO_x that contribute to poor air quality. Emissions to the air from ships cause harm to public health, contributes to visibility impairment and other detrimental environmental impacts.

Several of the USA's most serious ozone and PM2.5 non-attainment areas are affected by emissions from ships. Currently more than 30 major US ports along the Atlantic, Gulf of Mexico and Pacific coasts are located in non-attainment areas for ozone and/or PM2.5.

Air pollution from ships is expected to grow over the next two decades. Without any of the planned emission control strategies, by 2030, NO_x emissions from ships would be projected to more than double, growing to 2.1 million tons a year while annual PM2.5 emissions would be expected to almost triple to 170,000 tons. The North American ECA ensures that emissions from ships will be reduced significantly, delivering substantial benefits to large segments of the population, as well as to marine and terrestrial ecosystems.

7.2 Gas engine emissions

The main types of emission from the combustion process in an internal combustion are CO_2, NO_x, SO_x and PM (particle matter). The amount depends on the type of fuel and the combustion process.

CO_2 is a greenhouse gas that is among those responsible for global warming.

NO_x is formed due to high temperature and pressure during the combustion process and contributes to the formation of smog as well as contributing to the formation of ground level ozone.

SO_x cause acid rain and have a negative impact on public health. The emission amount is directly related to the amount of sulphur present in the fuel.

Secondary SO_x and NO_x also contribute to PM formation results through a series of chemical and physical reactions resulting in sulphate and nitrate PM. PM and black carbon are other solid pollutants created from the combustion process. PM results from various impurities and incomplete combustion processes. Most PM emissions are harmful to humans and may have contributing factors to global warming. The accumulation of black carbon on glaciers and polar icecaps may accelerate the melting rate by increasing the absorption of sunlight (United States Environmental Protection Agency, 2010). There is an increasing focus on black carbon emissions and its impact on environment and its contribution to global warming.

Unlike the limits in North America imposed on land based transport, power generation and inland waterways, there are currently no limits specified by IMO on emissions of Unburned Hydrocarbons (HC) or Carbon Monoxide (CO). The reason for this is considered to be simply that these are not the significant emission components from a well maintained diesel engine when operating under marine transit conditions. In the USA, the EPA have stipulated HC and CO limits for all engines, including the largest marine models.

In the case of gas engines, they have higher emissions of CO and HC than diesel engines. While regulations are not generally in place for these compounds in the commercial marine sector, this is most likely a result of the small number of engines. If Natural Gas engines become more widely used, CO and HC limits might be expected. There are treatment methods for reducing emissions of CO and HC in engine exhaust gas.

7.2.1 Greenhouse gases (CO_2, CH_4)

CO_2 emissions are related to the carbon content of fuel and the amount of fuel consumed. The CO_2 emission can be reduced by more improved fuel efficiency or by improvement in the vessel overall design and operating efficiency (trim management, route selection, reducing speed, improving ship hull forms, etc.).

The natural gas fuelled marine engines currently in use on the existing gas fuelled vessels in operation are medium speed, Otto cycle engines; either spark ignition or pilot fuel injection. Gas engines operating on the diesel cycle are also available, both as four stroke medium speed and two stroke low speed engines. Regardless of the operating cycle, method of natural gas ignition (spark ignited or diesel pilot), or the engine operating speed, using natural gas rather than fuel oils results in a reduction in the amount of CO_2 produced by the engine itself as a result of the lower carbon content.

This reduction in CO_2 production may be partially offset by methane slip, the term to describe the fraction of natural gas that passes through the engine without burning. Methane slip is more prevalent in engines operating on the Otto cycle. The amount of methane released by natural gas engines operating on the diesel cycle is comparable to operation on conventional liquid fuel. Manufacturers of Otto cycle natural gas engines are continuing to make advances in reducing the amount of methane slip by using a lean-burn principle. There is the potential to reduce methane emissions as a result of enhanced engine design, integration of methane-related controls, and the use of methane-targeted oxidation catalysts.

However, the total GHG emissions from the ‘well’ to ‘propeller’ using natural gas are getting more attention, and as current research indicates the LNG pathway will influence the actual benefits when compared to conventional fuel.[10, 14] Use of best practices in the LNG supply chain can reduce the amount of methane released to the atmosphere.

7.2.2 SO_x emissions

The amount of SO_x produced depends on the sulphur content of the fuel.

There are very small amounts of sulphur in the natural gas produced in North America. Therefore, when compared to conventional diesel fuels with sulphur content equal to the IMO limits, the amount of SO_x is significantly reduced.

While diesel ignition dual fuel or direct injection natural gas engines may potentially use higher sulphur content fuel oils for pilot fuel, the SO_x emissions from these types of engines are the sum of the contributions from the natural gas and pilot fuel. There are negligible SO_x emissions for a spark-ignited Otto cycle engine operating on gas only. There might be some small amounts because of combustion of the lubricating oils.

7.2.3 NO_x emissions

NO_x forms during combustion and is primarily a function of the temperature in the combustion zone. In a diesel cycle engine there is a flame front where the temperatures are very high and this forms NO_x. Generally, the higher the temperature, the more NO_x is produced. However, the formation of NO_x is a complex issue and several formation mechanisms are important. It is also dependent on the amount of excess air during the combustion process.

Diesel cycle engines, regardless of whether they are fuelled by natural gas or by fuel oils, have higher NO_x emissions compared to engines operating on the Otto cycle.

In the case of gas fuelled engines operating on the diesel cycle, SCR or EGR may be required in order to comply with the IMO Tier III NO_x limits, although the specific emissions management strategy will vary depending on the engine manufacturer.

In the case of gas fuelled marine engines operating on the Otto cycle, neither SCR nor EGR are required to comply when operating on gas only. However, in the case of dual fuel engines when operating on diesel fuels, SCR or EGR will be required to comply with NO_x III limits.

7.2.4 PM emissions

PM emissions can be attributed to incomplete combustion of fuels. High cylinder temperatures and pressures can cause some of the fuel injected into a cylinder to break down rather than combust with the air in the cylinder space. This breakdown of the fuel can lead to carbon particles, sulphates and nitrate aerosols being produced. Fuels with higher sulphur content result in higher PM emissions because some of the fuel is converted to sulphate particulates in the exhaust. However, sulphur is not the sole source of particulate matter. According to a recent study[6] natural gas PM emissions are reduced by approximately 85%.

7.3 Effect on environment

Because of the ECA and the more stringent emissions requirements for marine engines, ships will reduce their emissions of nitrogen oxides (NO_x), sulphur oxides (SO_x) and fine particulate matter (PM2.5). In 2030, according to EPA, emissions from these ships operating in the ECA are expected to be reduced annually by 1,300,000 tons for SO_x, 1,200,000 tons for NO_x and 143,000 for PM (2.5). The benefits are expected to include preventing between 12,000 to 31,000 premature deaths and relieving respiratory symptoms for nearly five million people each year in the US and Canada. The monetized health-related benefits are estimated to be between $110 and $270 billion in the US in 2030.

Based on EPA analysis, the US coastline and much of the interior of the country will experience significant improvements in air quality due to reduced PM and ozone from ships complying with ECA standards. Coastal areas will experience the largest improvements; however, significant improvements will extend far inland.

8
Technology readiness

8.1 Current LNG fuelled shipping

This section provides a summary of the LNG powered vessels currently in service or on order. The discussion in this section excludes gas carriers, which can use gas as a fuel but also carry gas as a cargo.

As of 15 November 2013, there were 44 vessels operating using LNG as a fuel and a further 44 vessels on order. The majority of vessels in service using LNG as a fuel are in Norway and the Baltic area. However, North America has seen a number of confirmed new build and conversion projects since 2012, including ferries (Canada), offshore supply vessels (US), container ships (US) and Great Lakes ore carriers (US).

The worldwide development of LNG fuelled fleet is shown in figure 40. About 15 of the confirmed orders for new build and conversions are in North America.

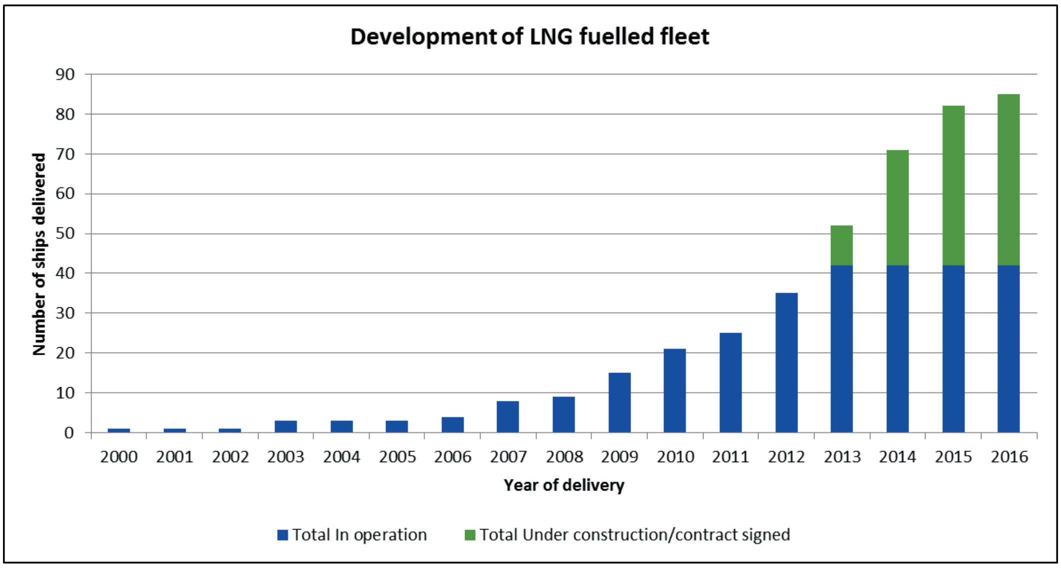


Figure 40: *LNG fuelled fleet*

Before 2011, all of the LNG fuelled ships were operating in Norway with most of vessels being coastal ferries or platform supply vessels (PSV). The development of the LNG fuelled ships in Norway was driven by the environmental considerations and financial incentives from the Norwegian government.

In regards to the engine technology used for the LNG fuelled ship segment, the next figure shows the technology used for the ships in operation as well as for the ships on order.

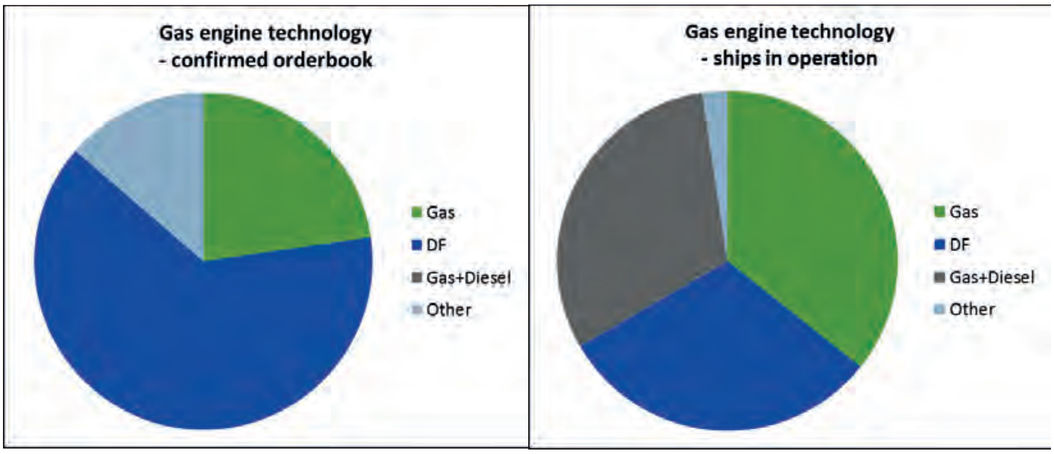


Figure 41: *Engine technology*

In the figure, gas means ships with gas-only engines, DF means ships with dual fuel engines, gas+diesel means ships with both gas and diesel engines, and other means ships with gas turbine or where the engine technology has not been published.

In the table below there is a summary of number of ships by type and operation area.

Type of ship	Number	Operation area
Vessels in Service		
Small coastal ferries	20	Northern Europe
High speed ferry	1	South America
Large cruise ferries	2	Northern Europe
Offshore vessels	12	North Sea
Product tanker	1	Northern Europe
Inland waterway	2	Northern Europe, China
Misc., patrol, fish farm	5	Northern Europe
Harbour vessels	1	Korea
Total	**44**	
On Order/Under Construction as of November 2013		
Small coastal ferries	10	Canada (3), Northern Europe (7)
Offshore vessels	10	USA (6), North Sea (4)
Ro-pax vessels	1	Northern Europe
Tugs	4	Northern Europe (2), China (2)
Patrol vessel	1	Northern Europe
Liquid ethylene carriers	3	
Cargo, product vessels	3	Northern Europe
Ro-ro vessels	4	Northern Europe
Ro-ro vessels (conversion)	2	USA
Container vessels	6	USA (4)
Total	**44**	

8.2 Storage and arrangement on board

Carriage of LNG on board ships started with the first LNG carriers over fifty years ago and there are currently about 380 LNG carriers in operation with about a 100 on the order books. The development of the gas carrier fleet has also resulted in different types of tank and LNG storage designs.

The LNG carriers are designed following the requirement in the ICG code and the following tank types for carrying LNG as a cargo are defined in this code.

- Independent tanks
  - Type A
  - Type B
  - Type C
- Membrane tanks with full secondary barrier

In addition to the specific tank design, the size requirement and tank location are important considerations for a gas fuelled vessel. The handling of any boil off from the tank is also an issue to be considered.

In the IMO Interim Guidelines for Gas Fuelled Ships, MSC 285(86), LNG storage tanks used for gas fuelled ships are to be independent tanks, either Type A, B or C, designed in accordance with Chapter 4 in the IGC Code. For the current fleet of gas fuelled ships in operation only Type C tanks have been used. However, in accordance to the draft IGF Code, the use of membrane tanks will also be possible as fuel tanks for gas fuelled vessels. Additionally, the draft IGF Code opens for accepting use of portable tanks, i.e. tank containers.

8.2.1 Type A Independent Tanks

These are prismatic tanks designed primarily using recognized standards of classical ship-structural analysis. Because of the prismatic design, the vapour pressure should not exceed 0.7 bar. These also require a complete structural secondary barrier.

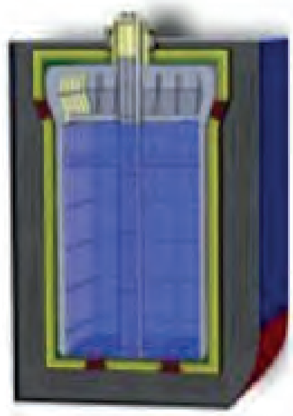


Figure 42: *Prismatic Independent Type A tank*

8.2.2 Type B Independent Tanks

These are tanks that are designed using model testing and analysis method to determine stress levels, fatigue life and crack propagation characteristics. They can be of prismatic design, but the well-known spherical Moss tank design is a Type B tank. The design vapour pressure is typically 0.25 bar. They only require a partial secondary barrier.

Type B tanks may be used in larger or longer endurance vessels, as they can maximize the amount of storage volume in an internal installation on the ship. To date, there are no LNG fuelled vessels with Type B tanks in service or under construction, though several designs have been proposed and some have received Approval in Principle.

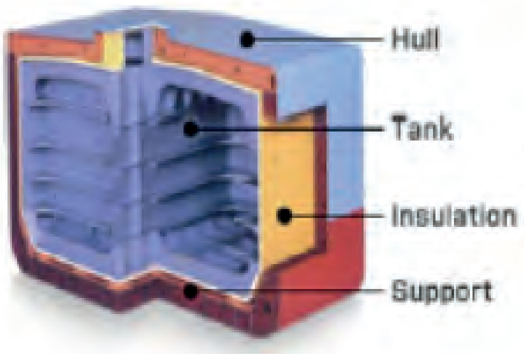


Figure 43: *Prismatic Independent Type B tank*

8.2.3 Type C Independent Tanks

These are essential pressure vessels which are designed in accordance with the relevant pressure vessel design code. The working pressure is typically less than 10 bars for tanks up to 700 m^3. Type C tanks are considered leak proof, and no secondary barrier is required. The outer shell of the tank is a low temperature resistant material, typically stainless steel. Most of the tank designs for the gas fuelled ships in operation, other than LNG carriers, are using vacuum insulated Type C tanks.

Figure 44: *Independent Type C tank*

8.2.4 Membrane Tanks

Membrane containment systems, such as GTT's Mark III and NO96 systems, are commonly used on LNG carriers. Membrane tanks typically consist of two independent and liquid tight barriers and two layers of insulation to protect the hull from the low temperatures and to limit boil off.

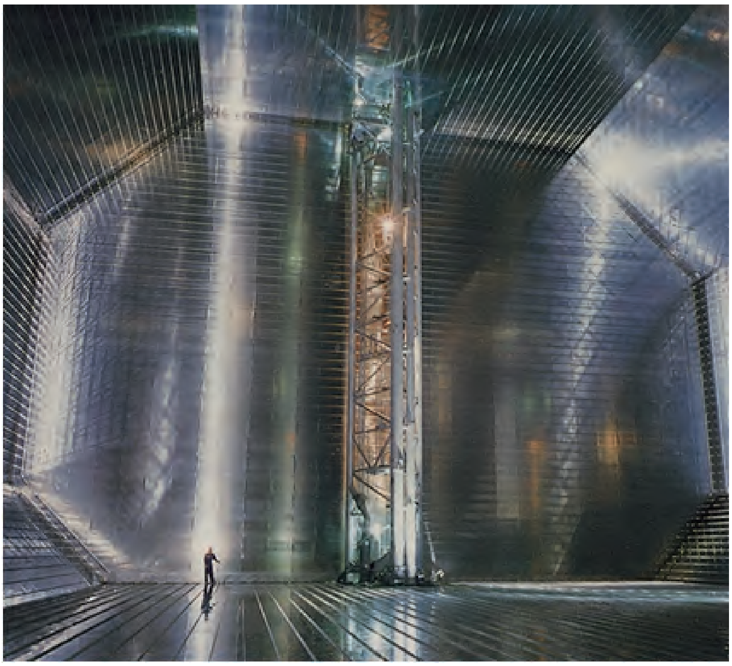


Figure 45: *Membrane tank*

8.2.5 Boil off handling

All storage tanks for LNG are highly insulated but gradual heating is unavoidable which results in boil off gas (BOG) which has to be managed. For vessels fitted with Type C tanks, the BOG can be managed up to a point by allowing the pressure to increase. The draft IGF Code requires that the tank pressure shall be kept below the set point of the pressure relief valves without venting gas to atmosphere.

The draft Code indicates various methods for tank pressure control:

- re-liquefaction of vapours
- thermal oxidation of vapours
- pressure accumulation
- liquefied gas fuel cooling
- energy consumption by the ship (in idle condition)

The minimum holding time is 15 days for pressure vessel tanks (Type C tanks) as proposed in the draft IGF Code. The USCG requires a minimum of 21 days.

In the case of tanks with a design pressure of maximum 0.7 bar, i.e. tanks other than Type C tanks, combustion (burning, oxidation) of the BOG is probably the realistic alternative.

A sketch of a gas supply and BOG handling system is in figure 46.

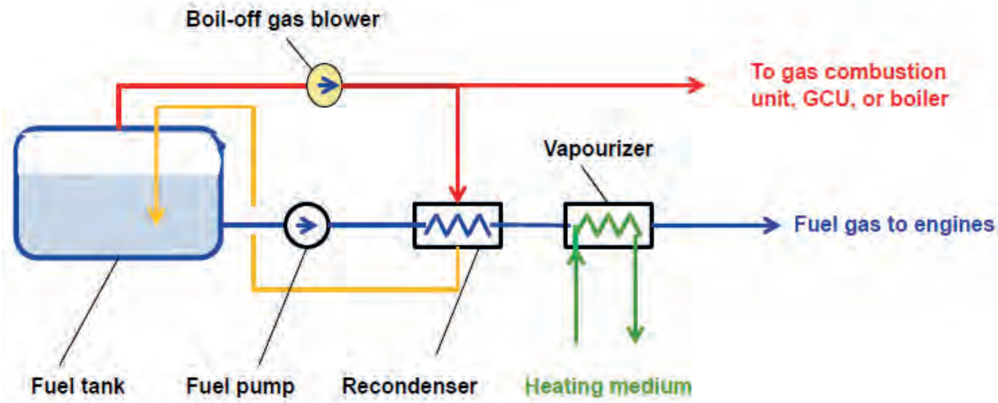


Figure 46: *Gas supply and BOG handling system*

8.2.6 Tank location

The location of the LNG storage tank or tanks is also important from a safety point of view. The IMO Interim Guidelines allow LNG tanks to be located both below and above deck, but the position of the tanks is subject to restriction on the distance from the side and the bottom of the vessels. Tanks located on deck will also need to be protected from mechanical damage, e.g. from dropped objects, cargo handling cranes, etc.

In the current IMO Interim Guidelines the tank location is subject to prescriptive requirements based on the tank size and breadth of the vessel.

There have been some discussions during the development of the draft IGF Code whether a risk based method should be developed for determining the tank location.

8.2.7 Fuel supply arrangements

IMO resolution MSC 285(86) requires a fully redundant system. For single fuel installations (gas only), the fuel storage should be divided between two or more tanks of approximately equal size. Dual fuel engines may use a single gas tank and have liquid fuel as a backup. There are some interpretations of this rule, and some applications may allow a single fuel, pure gas system to have only one fuel storage tank provided that there is redundancy in the fuel delivery systems.

8.3 Engine technology

The use of gas as a fuel for prime movers is not something new. Many of the very early inventions of internal combustion engines were operated on gas, and the engine invented in 1876 by Nikolaus Otto ran on coal gas. This engine used four cycles in the operating process and this process is today known as the Otto cycle. However, liquid petroleum based fuels become the preferred fuel for the modern versions of the internal combustion engines.

The prime movers that are available for use on board ships to generate power is as follows.

- Reciprocating internal combustion engine (diesel or Otto cycle)
- Gas turbines
- Fuel cells
- Fossil fuelled steam turbine
- Nuclear reactor with steam turbine

Except for nuclear power, all prime movers can use both liquid fuel and gas fuels. The diesel engine has become the predominant engine technology for marine applications because of relatively low cost and high fuel efficiency. Steam turbine powered ships have mostly been phased out, except for older LNG carriers, due to the simplicity of using boil off gas as a fuel for these ships. There are also a few US flagged steam turbine ships in commercial operation.

The gas turbine, the gas here referring to the working fluid rather than the fuel, is also used on some ships, primarily on naval ships and high speed vessels, because of the high power to weight ratio.

Fuel cells have been used on surface ships for research and testing purposes, and it could be a possible technology in the future.

8.3.1 Natural gas engine technology

This section will focus on the state of the technology for internal combustion engines designed to operate on gas fuels. There are three basic technologies used in natural gas engines – lean burn spark-ignition pure gas, dual fuel with diesel pilot and direct injection with diesel pilot. The engine technology can also be divided into which thermodynamic cycle is used by the engine, either the Otto cycle or the diesel cycle.

The basic characteristics of these two cycles are defined in the table below.

Combustion cycle	Fuel injection	Ignition
Otto	The fuel is mixed with air and admitted to the cylinder before the compression starts.	The Otto cycle combustion is started by an ignition source, typically an electric spark or injection of pilot oil.
Diesel	The fuel is admitted to the cylinder first at the end of the compression stroke.	Combustion is usually started by self-ignition of the fuel, also called compression ignition.
Combined cycle dual fuel	In gas mode – the above Otto cycle process is used. In diesel mode – the above diesel cycle process is used.	In gas mode – usually started by injection of pilot fuel oil into the compressed mixture of air/natural gas. Normal diesel cycle ignition in diesel fuel only mode.
Diesel cycle dual fuel	In both gas and diesel modes – the fuel is admitted to the cylinder first at the end of the compression stroke.	In gas mode – pilot fuel is injected and self-ignites; gas is then injected into the flame from the pilot oil.

The technology available for the marine market is shown in the next table. All of the engines in use on the gas fuelled ship in operation are either pure gas engines or dual fuel four stroke medium speed engines. Engines classified as low speed typically operate up to 300 RPM, medium speed engines typically operate in a range of 300 to 1000 RPM, and high speed engines operate at 1000 RPM and above. A summary of the gas engine technologies is shown in table 17.

Table 17 – *Natural gas engine technologies*

	Pure gas engines	Dual fuel 4-stroke engines	Dual fuel 2-stroke engines
Cycle	Otto	Otto	Otto/diesel
Gas supply	Low pressure	Low pressure	Low/High pressure
Ignition source	Spark plug	Liquid fuel pilot	Liquid fuel pilot

The engines which operate with the Otto cycle use a pre-mixed air/fuel charge, and this results in the following two issues which are not seen with the diesel cycle gas engines:

- Sensitivity to gas quality: Lower methane-number fuels increase the susceptibility to knocking.
- Methane slip: Unburned fuel from incomplete combustion will escape in the exhaust and be released to the atmosphere unless removed by after treatment.

All the major engine manufacturers offer different options and sizes for natural gas engines, either pure gas engines or dual fuel engines. A summary is provided in the next paragraphs.

8.3.2 Pure gas engines

The engines are available for the marine market and have been applied to many of the existing gas fuelled ships both for diesel electric and mechanical propulsion arrangement. The majority of the gas engines on board the gas fuelled ships are medium speed engines.

Power range for available marine engines are from about 500 kW to almost 10,000 kW with up to almost 500 kW/cylinder.

Examples of major manufacturers with pure gas engines for the marine market are Rolls-Royce and Mitsubishi.

8.3.3 Dual fuel four-stroke engines

As the name implies, a dual fuel engine can either operate on gas fuel or on diesel fuel, or with some combination of diesel and gas. The switching or change between the fuels is considered to be seamless on the modern dual fuel engines and there should be no interruption in the operation of the engine.

Power range for available marine engines is from about 500 kW to almost 18,000 kW with up to 1000 kW/cylinder.

Examples of major manufacturers with dual fuel four stroke engines for marine use are MAN, Wärtsila and Caterpillar MAK.

8.3.4 Dual fuel two-stroke engines

Dual fuel two-stroke engines for the marine engine market could either be medium speed engine or low speed engine.

In the low speed market, there have not been any dual fuel engines installed on a ship; however, MAN have received Type Approvals for the ME-GI design which operates with high pressure gas supply and according to the diesel cycle with direct injection of the gas. MAN has received orders for the ME-GI engine for several new build projects.

The other main manufacturer of low speed engines, Wärtsila, recently announced that they had successfully completed a full scale test of its dual fuel engine, the RT-flex50DF. The engine will operate with low pressure gas supply and according to the Otto cycle.

The US manufacturer, EMD (Electro Motive Diesel), are producing two stroke medium speed engines very popular in North America for the locomotive and marine workboat market. The company are developing dual fuel engines, including for the marine applications. One of the technologies that EMD is developing is called 'dynamic gas blending' that allows the engine to operate within a wide range of diesel/gas blending ratio. This technology is low pressure and operating according to the Otto cycle.

8.4 Safety of LNG

The properties of LNG are described in Appendix B, including the risks and safety issues involved in handling of natural gas and LNG. The main safety challenges of using LNG as a fuel are the following;

- Fire and explosion risk
  - Flammable in range of 5% to 15% mixture in air
  - Natural gas is odour- and colourless
- Low temperature of liquid gas / cold jets from compressed natural gas – LNG at –163°C
  - LNG in liquid state or cold gas can generate severe chill injuries
  - Normal ship steel will be very brittle and can fracture if exposed to LNG
- Gas tank large energy content
  - Protection from ship side and bottom (collision and grounding)
  - Protection from external fire and BLEVE (boiling liquid expanding vapour explosion)
  - Protection from mechanical impact

The basic principles in the safety philosophy and risk mitigation used in the design and operation of LNG facilities are illustrated in figure 47, and these principles are also applied in rules and standards developed for the LNG fuelled ships.

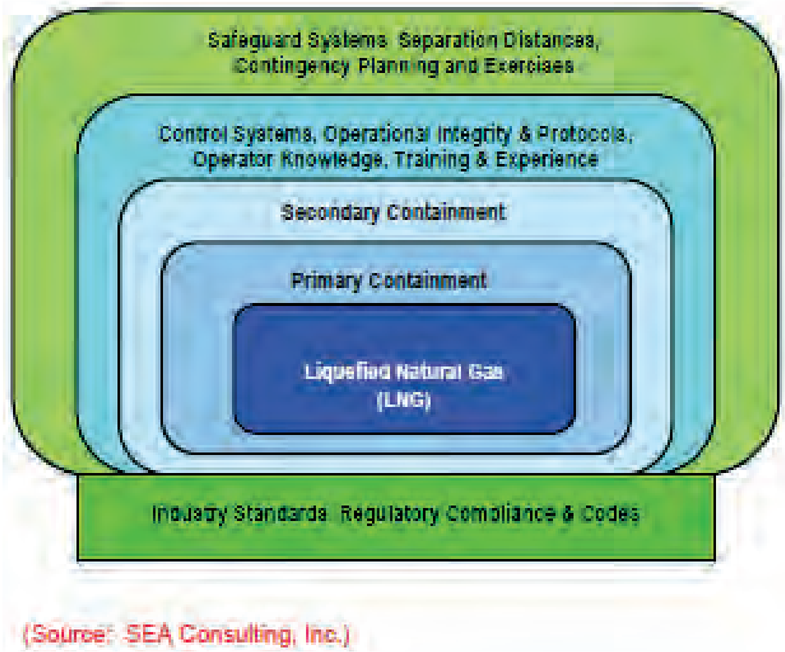


Figure 47: *LNG safety levels*

The IMO Interim Guidelines and the upcoming IGF Code are focused on specifying the barriers needed in order to reduce the level of risk by specifying the requirement for the design of the LNG fuelled ships and the onboard system.

The development is based on the experience gained from the existing gas carriers and the fleet of LNG fuelled ships that have been built and are in operation.

8.5 Human Resources and competence

The competence, training and certification of the personnel involved in the design, maintenance, operation and emergencies related to LNG as a marine fuel are also critical factors. The LNG carrier industry has been operated without any major incidents related to the design and operation of the LNG fleet and the LNG terminals. However, the vessel crews and shore side personnel involved in the operations were specialized with training and using relatively standardized procedures and equipment. With the current growth in LNG fuelled shipping, the challenge will be to maintain and ensure the appropriate competence for the personnel involved in LNG as a marine fuel. Understanding the risks and the proper safety barriers are needed for vessel/equipment design personnel, certification authorities, shipyards/manufacturer, bunker operators and vessel crew. A serious incident involving an LNG fuelled vessel in the early adoption phase could be detrimental to the risk perception of the public and the policy makers.

The development of guidelines and requirements for personnel certification is underway, and there is demand for courses and training that address the specific needs and certification of the personnel involved with LNG fuelled ships.

The ongoing work by IMO and ISO to develop competence and training standards and codes for the industry will take some time because of work processes, and other stakeholders will also need to focus on the competence development. Classification societies are addressing this issue by development of personnel certification standards, recommended practices and training courses.

The formation of the organization for gas fuelled vessels, Society for Gas as a Marine Fuel (SGMF), is also expected to be an enabler for competence development as one of the goals is to develop best practice for the use of LNG as marine fuel.

In USA, the USCG has issued the draft policy letters related to personnel involved with LNG fuelled ship operations and bunkering (USCG Draft PL No. 01-13).

In Canada, West Coast Marine Liquefied Natural Gas (LNG) Supply Chain Joint Industry Project[4] will also provide specific recommendations and proposed course outlines for the training of all personnel involved in the LNG fuelled shipping, from the designers to the emergency responders.

It is important that the competence development, personnel certification and training initiatives are being prioritized and supported as this will facilitate the growth in LNG fuelled shipping.

9 Conclusions

9.1 Key trends

The environmental and economic benefits of using natural gas stored in the form of LNG as a fuel for shipping, as well as the multi-modal use, have created a lot of interest in the business community and among other stakeholders in USA and Canada. This includes federal and local governments, industry groups, and environmental organizations. The main driver is the IMO regulations, the anticipated abundance of the natural gas supply in North America, and the relative low cost of natural gas compared to oil-based fuels.

The North American ECA is an area of high shipping activity, both with respect to international and domestic vessel traffic. It is expected that the shipping activity in most segments and region will have moderate growth in the near future, but the offshore vessel and tanker traffic in the Gulf of Mexico is expected to a see a higher growth rate.

The Gulf of Mexico, Pacific Northwest, Great Lakes and the Eastern Seaboard of USA and Canada are the regions where LNG fuelled shipping will develop initially and this is evident from the projects that have been announced. The development of an LNG infrastructure is underway in these regions to support the anticipated growth in the domestic and regional demand.

This will also enable international shipping operating in the North American ECA to take advantage of the growing infrastructure located in the major port and shipping hubs.

Early adopters in both USA and Canada have embraced the technology and benefits of using LNG as fuel for ships, and the number of confirmed projects in the last couple of years is an indication that the foundation is laid for further growth.

It is also evident that in North America, the decision of using LNG as a fuel is mostly based on the financial attractiveness of the option. Therefore, many of the LNG fuelled vessels on order are ocean going cargo vessels, which is different than most of the existing LNG fuelled ships in Northern Europe, and the development in North America could be an enabler for more use of LNG as a fuel also for international shipping.

9.2 Potential for LNG fuelled ships

In order to comply with the existing and future emission regulations and restrictions inside an ECA, the following options are available for vessels that are subject to the regulations in MARPOL Annex VI.

1. Use of low sulphur diesel fuel
2. Use of alternative fuels
3. Use of abatement technologies, typically exhaust gas treatment system

This study has been tasked to evaluate the feasibility of LNG as the alternative fuel option; however, it is noted there are other alternative low flash point fuels that are also considered by the industry.

Table 18 shows an overview of the alternative and a comparison of the main differentiating factors to be evaluated (Adopted from[3]).

Table 18 – *Comparing the alternatives: LNG, MGO and HFO*

	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

The preferred solution from an environmental compliance perspective is the use of LNG as a fuel; however, the compliance strategy chosen for a vessel will depend on a number of factors, with the most important being the financial comparison of the options.

The major parameters that will influence the financial analysis are:

- Cost of installation and equipment
- Time spent inside the ECA
- Cost of LNG compared to diesel fuels (residual and distillate)

The future environmental regulations will also influence the decisions; a postponement of the global limits of sulphur content in marine fuel would likely reduce the growth of LNG fuelled ships engaged in international trade.

The worldwide future availability of LNG and the supply of proper diesel fuel qualities, both distillate and residual, are also factors that need to be evaluated when the compliance strategy is being decided.

The ship segments in North America that are expected to be the first adopters of LNG as a fuel are vessel operating inside the ECA and vessel engaged in short sea shipping, e.g. ferries, OSVs, container/ro-ro and tankers. The current project list of LNG fuelled ships in North America confirms the potential of these vessels being the first to use LNG as a fuel.

9.3 LNG infrastructure development

The existing natural gas pipeline network and infrastructure in North America is an important factor in the development of the LNG supply chain and infrastructure. The extensive pipeline network, especially in the southern and eastern part of the US, enables the transportation of natural gas to the optimal areas and locations. There are several plans for build-up of the LNG infrastructure already in place both in USA and Canada and this development is expected to continue. Several of the projects are focused on delivery of LNG as fuel to shipping, in addition to supplying LNG for multi-modal transportation use.

Several LNG pathways and bunkering methods are being evaluated and the choice will depend on the vessel types, as well as on the regulations and guidelines being developed to ensure safe practices. Even as the price of pipeline natural gas is low, the price of LNG delivered to ships tanks (FOB) depends on the liquefaction cost and the bunkering cost margin. The expected LNG price (FOB) in North America is subject to uncertainty before the market has been developed and there is both a supply and a demand.

Even with the future potential for LNG export from USA, it is not considered that this will have a great impact on the domestic natural gas price. However, the LNG export market will be coupled to the worldwide LNG demand and this will influence the business decision for the operators of the large-scale LNG export facilities.

Another factor that will drive the cost of LNG available as a ship fuel is how the market will develop. One scenario is that the market will be dominated by one or only a very few suppliers. The pricing of LNG as a marine fuel might then be closer coupled to the marine diesel fuel pricing. Another scenario is that the market becomes more competitive, including the multi-modal use of LNG, and the market forces will create a more competitive environment.

9.4 Regulatory regime

An appropriate regulatory framework will be one of the key enablers for the use of LNG as a ship fuel as safety is a crucial issue for all stakeholders.

The international regulations applicable to LNG as a fuel for shipping are developed by IMO, standard organizations (ISO, IEC, EN, etc.), classification societies and industry groups. IMO is in process of development of the IGF Code, *International Code of Safety for Ships using Gases or other low Flashpoint Fuels*. This code will be referenced within SOLAS and have requirements for the construction and operation of gas fuelled ships. The timeline for adoption and ratification of the IGF Code is still uncertain, and in the meantime flag States will need to use the IMO Interim Guidelines, MSC.285(86), and the classification societies rules for guidance.

ISO is developing a standard related to the bunkering systems and equipment for supplying LNG as fuel to ships. A draft version of this document was published as ISO/DTS 18683: Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships, on 29 June 2013.

Most IACS members have issued rules and guidelines related to the design and safety requirements for the gas fuelled ship and onboard systems. In addition to the ship rules, class societies are developing guidelines and standards related to the bunkering operation and personnel certification.

The national regulatory framework within USA and Canada must also be in place to ensure the safe and secure use of LNG as a ship fuel as well as to support the adoption of the expected increase in demand. Both in the US and Canada, the regulations pertaining to the LNG facilities and infrastructure is governed by different federal (national) jurisdictions and agencies, as well as local regulatory entities.

In USA, the USCG has the responsibility for the US flag and port state regulations for the design, construction and operation of LNG fuelled ship. The USCG has issued a policy letter to accept the design of gas fuelled ships based on IMO MSC.285(86). There are two policy letters related to bunkering operations and bunkering facilities to be released after an internal process. In addition to the USCG, there are several other federal agencies that have regulations and responsibilities that could apply to LNG fuelled shipping operations and bunkering facilities. There are also State and local agencies that might have oversight and regulations, including each State's Department of Environmental Protection and local Fire Department (Fire Marshal).

In Canada, Transport Canada is the federal agency that regulates shipping in Canada, including the flag regulations for Canadian flagged vessel. The Canadian regulations currently do not permit the use of LNG as ship's fuel and the IMO Interim Guidelines are not incorporated by reference in any Canadian regulation. However, there is work in progress in order to develop a regulatory framework to accepting the use of LNG as fuel for Canadian vessels. There is currently a process in place (MTRB – Marine Technical Review Board) which would allow for LNG vessels to visit Canadian ports.

The West Coast Marine Liquefied Natural Gas (LNG) Supply Chain Joint Industry Project[4] identified existing Canadian regulations applicable to LNG fuelled ships and will provide recommendations for the policy development of a Canadian regulatory framework with respect to design and construction of LNG ships, operation of LNG fuelled ships in Canadian waterways and ports, bunkering of LNG fuelled ships, and measures to prevent security incidents. It is generally proposed that the framework be based on reference to the international codes and guidelines that are in place or in development, and also use the existing Canadian processes and regulations, e.g. TERMPOL and MTRB.

9.5 Environmental benefits

The environmental benefits of using LNG as fuel are significant. Compared to the use of diesel fuel, use of LNG will reduce the NO_x emission by approximately 90% on a lean burn gas fuelled engine, and the SO_x and particle matters emissions are negligible without the need on any abatement technologies. The CO_2 emissions are about 20% lower compared to diesel fuel because of the lower carbon content. However, the overall effect on GHG (Green House Gas) emissions needs further study.

9.6 Technology readiness

The design of LNG fuelled ships, as well as the onboard systems and technologies required to use LNG as a marine fuel, can be considered proven and mature, though development is continuing at a rapid pace in such areas as engine technology and onboard storage systems. As of 15 November 2013, there were 44 vessels operating using LNG as a fuel and a further 44 vessels on order. Engines are available in both dual fuel and pure gas types to cover the majority of ship propulsion needs.

In regards to existing LNG fuelled ships in operation, only Type C independent tanks have been used, but approvals in principle have been given by classification societies for both Type A and Type B independent tanks. Additionally, the IGF Code also opens for accepting use of portable tanks, i.e. tank containers. Handling of boil off gas and vapour recovery during bunkering and venting are also subject issues that can be solved technically.

The issue of tank location is subject to discussions in order to minimize the risk for leaks during collisions, groundings or mechanical damage. This is an important issue as the size of the LNG vessels and storage tanks is increasing, together with more vessel operations in areas with higher traffic density and different ports.

9.7 Safety and human factors

One of the key elements is that there is understanding by all the stakeholders of the safety and risk of the storage, transportation and use of LNG. If incidents or a serious accident would occur at an early stage of the introduction of LNG as ship fuel, this could constitute a serious barrier for further development and expansion of the use of LNG as ship fuel. Therefore it is of utmost importance that stringent safety standards and regulations are developed and implemented for LNG bunkering and for the operation of LNG fuelled vessels.

There is ongoing work and initiatives internationally, as well as in USA and Canada, to develop competence and training standards for vessel/equipment design personnel, certification authorities, shipyards/manufacturer, bunker operators and vessel crew. Classification societies are addressing this issue by development of personnel certification standards, recommended practices and training courses.

It is important that the competence development, personnel certification and training initiatives are being prioritized and supported as this will facilitate the growth in LNG fuelled shipping.

Excellent safety records from many years of large-scale LNG carrier operations demonstrate that it is possible to control LNG hazards efficiently by adequate design, stringent regulations and competent personnel.

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Pilot study on the use of LNG as a fuel for a high speed passenger ship from the Port of Spain ferry terminal in Trinidad and Tobago

TRINIDAD AND TOBAGO

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TRINIDAD AND TOBAGO

List of abbreviations and acronyms

ADR	International Carriage of Dangerous Goods by Road (European Agreement)
BOG	Boil Off Gas, evaporated LNG formed above the tank level surface in LNG tanks
CAPEX	Capital Expenditures
CARICOM	Caribbean Community and Common Market
CFR	The Code of Federal Regulations (U.S.)
CNG	Compressed Natural Gas
CH_4	Methane
CO_2	Carbon Dioxide
CTS	Container to Ship (LNG bunkering mode)
DMA	Danish Maritime Authority
DNV	Det Norke Veritas
dwt	Dead Weight Tonnage (tot weight of a ship's cargo, fuel, etc.)
ECA	Emission Control Area
EIA	Environmental Impact Assessment
EMSA	European Maritime Safety Agency
ESD	Emergency Shut Down system
ESD2	ERS linked to the ESD system
EU	European Union
EUR	Euro currency
Ex-zone	Flammable gas atmosphere with special requirements for electrical equipment
FMEA	Failure Mode and Effect Analysis
FO	Fuel oil, all types of oil based marine fuels used today such as MDO, MGO, HFO
FOB	Free On Board, fuel price condition defined by the Incoterms 2010, International Chamber of Commerce
GHG	Green House Gas, emissions of GHG gaseous substances influences the greenhouse effect and contributes to global warming and the climate change
GL	Germanischer Lloyd
GT	Gross Tonnage (an index of ship's overall internal volume)
HAZID	Hazard Identification
HFO	Heavy Fuel Oil
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
IGF	International Code of Safety for Ships using Gases or other Low Flashpoint Fuels (IGF Code)
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
ISO	International organization for standardization

ITPS	Intermediate tank via pipeline to ship
LNG	Liquefied Natural Gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
mmcfd	million cubic feet
mmpta	million tonnes per annum
NFPA	The National Fire Protection Association (U.S.)
NCV	Net calorific value
NG	Natural Gas, a fossil fuel consisting primarily of methane, but commonly also includes some higher hydrocarbons, carbon dioxide and nitrogen
NGC	The National Gas Company of Trinidad and Tobago
NO_x	Nitrogen Oxides
OPEX	Operating Expenditures
PM	Particulate Matter
SCR	Selective Catalytic Reduction (NO_x reduction for exhaust emissions)
SECA	Sulphur Emission Control Area
SGMF	Society For Gas as a Marine Fuel
SO_2	Sulphur Dioxide
SOLAS	The International Convention for the Safety of Life at Sea
SO_x	Sulphur Oxides
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
STS	Ship to ship bunkering (LNG bunkering mode)
ToR	Terms of Reference
TTD	Trinidad and Tobago Dollar currency
TTIT	The Trinidad and Tobago Inter-Island Transportation Company Ltd
TTS	Truck to ship bunkering (LNG bunkering mode)
UN	United Nations
UNECE	United Nations Economic Commission for Europe
USD	US Dollar currency
WCR	Wider Caribbean Region

Conversion factors

The following conversion factors and units have been used in the calculations presented in the report.

Conversion factors	Unit	Unit
Density of LNG	0.43	tonne/m^3
NCV of LNG (Net calorific value)	13.7	MWh/tonne
NCV of LNG (Net calorific value)	46.746	MMbtu/tonne
Density of MDO	0.89	tonne/m^3
NCV of MDO	11.6	MWh/tonne
1 MMBtu (million British thermal unit)	0.293	MWh
1 GJ (Giga Joule)	277.78	kWh
1 MMBtu (million British thermal unit)	1.0546	GJ
1 m^3	35.315	cft
1 cft (cubic feet)	0.028317	m^3
1 m^3	264.17	gallon
1 gallon	0.003785	m^3
1 m^3	6.2898	oil barrel
1 oil barrel	0.15899	1 m^3
EUR/USD	1.3	
TTD/USD	0.156	
ROI, rate of interest	8%	

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Summary

This pilot study on the use of LNG as fuel for high speed passenger ferries between the sister islands Trinidad and Tobago provides decision support and background information to the operators of the ferry services for detailed business case analyses. The study may also serve as guidance for other early adopters of LNG as a ship fuel.

SSPA has compiled information from site visits, meetings and analyses and the report includes six main chapters addressing the background, route specific conditions, LNG supply chain, regulations, safety issues, cost estimations, and recommendations.

The present fleet of high speed ferries comprises two diesel powered aluminium wavepiercing catamarans that service the route with two to three round trips per day. Short travel time, low fare and regularity are appreciated by the travellers. The service is considered a national interest, and is subject to governmental financial support.

The following three optional LNG supply chains have been analysed and compared in terms of their capacity, cost and safety:

- LNG road truck from an existing LNG plant to the bunkering of the ferry at berth
- Local, small-scale liquefaction plant and supply by truck or pipeline to the ship
- LNG bunker barge from an LNG export terminal to bunkering of the ferry at berth

Transportation from the source and bunkering by road truck offers the lowest supply cost, but is limited with respect to capacity. Concerns were also identified with respect to the present road standard and risks for delays and traffic accidents. Local, small-scale liquefaction plants may also offer competitive options and by establishment in Tobago, advantages may be gained by more spacious terminal areas compared with the Port of Spain terminal. The LNG bunker barge option is favourable from a safety perspective, but requires large investments in loading facilities and is therefore only competitive if additional LNG customers are projected to be serviced in Port of Spain.

No regulative showstoppers have been identified for the reconstruction or newbuilding of LNG fuelled, high speed ferries, but the process requires close cooperation between the ship designers, flag State authority, classification society, and the operator. The cost for reconstructing the existing high speed craft is high, and includes the replacement of existing diesel engines with less bulky gas turbines and the installation of vacuum insulated LNG fuel tanks on the car deck.

The prospects for finding solutions that combine high environmental performance and reduction of overall operational costs via reduced governmental fuel oil subsidy expenditures are good, but the initial costs are high, and the investment strategies should include long term potentials for expanding the LNG fuel market.

For other stakeholders and member states that are conducting similar pilot studies on ship conversion or replacement, it is recommended to include careful LNG supply chain assessment, and the importance of early cooperation with projected LNG suppliers and a continuous dialogue with regulative authorities is stressed in order to minimize project risks and to ensure successful operation with LNG as ship fuel.

TRINIDAD AND TOBAGO

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TRINIDAD AND TOBAGO

1
Introduction

1.1 Background

The International Maritime Organization (IMO) has a special responsibility for the regulation of international shipping, safety at sea, and the prevention of marine pollution. There are four designated Emission Control Areas (ECAs) in effect globally including the US Caribbean Sea ECA which entered into force in January 2013. The ECA designation has proven effective for the reduction of harmful emissions from ships and the improvement of air quality. More ECA designations are therefore being discussed, and the entire Wider Caribbean Region (WCR) might be covered by ECA requirements in the future. One ECA compliance strategy is based on a shift from conventional oil fuel to LNG for propulsion of the ships. This strategy is considered specifically attractive in the WCR due to LNG's availability in this region and the favourable price situation of LNG in this region compared to other global natural gas markets. In the WCR a shift from conventional oil fuel to LNG may be economically motivated even without any SECA requirements and the environmental benefits is then to be seen as an extra bonus.

In 2012, the IMO financed a feasibility study on LNG fuelled short sea and coastal shipping in the WCR (SSPA, 2012). The feasibility study was conducted by SSPA Sweden and White Smoke and concluded that the prospects for introduction of LNG as ship fuel in the region were favourable. The report was presented at a workshop arranged by RAC-REMPEITC-Caribe in Trinidad and Tobago and the workshop meeting recommended that a regional pilot programme for the testing and implementation of LNG as a ship fuel in the WCR should be initiated and supported. The Port Authority of Trinidad and Tobago (PATT) was identified as a potential candidate for running such a pilot programme in cooperation with the Maritime Services Division of Trinidad and Tobago and the regional IMO office. Trinidad and Tobago's request for funding of the project was supported from the IMO's Integrated Technical Cooperation Fund and in 2013 SSPA Sweden AB was assigned the tender from IMO for the pilot study.

This report presents the result of the pilot study conducted by the consultant SSPA Sweden with its sub-consultants White Smoke and LDG during the fall of 2013. Statements and recommendations are formulated by the consultants and do not necessarily reflect the opinion of the local recipient or the financing parties.

1.2 Objectives of the pilot study

The objective of the study is to identify, outline and recommend a way forward for the accomplishment of a pilot implementation of an LNG fuelled, high speed passenger ship operating from the Port of Spain ferry terminal. The report provides background data for a detailed business case to be elaborated by the Port Authority PATT and TTIT and to facilitate further preparation of detailed specifications and processes for realization of the pilot project.

An increased use of LNG instead of traditional bunker oil as fuel for ships will reduce the harmful emissions of sulphur oxide, nitrogen oxide, and particles, and thereby to improvement of air quality and health in coastal societies that are exposed to ship emissions. The dissemination of this report might also provide guidance and encouragement for potential followers to consider and initiate further projects on LNG fuelled ship services in the WCR.

1.3 Scope and methodology

The scope of this pilot study on the use of LNG as ship fuel for high speed ferries operating from the Port of Spain ferry terminal includes six main components that are listed and structured in the report chapter numbers below. Two on-site visits for meetings and collection of information were conducted by the consultants in

September and November 2013, and analyses have been performed in Sweden by SSPA, White Smoke, and LDG.

Table 1 – *Report structure and components of the pilot study according to the assignment*

Component of ToR/Report chapter number	Description
Component 1/Chapter 2 Current traffic and future requirements	Identify, with the involvement of the Port Authority of Trinidad and Tobago, the requirements for an LNG fuelled fast passenger ship operation from the Port of Spain Ferry Terminal including the current and forecasted passenger numbers and current and prospective routes.
Component 2/Chapter 3 LNG supply chain and bunkering infrastructure	Identify and appraise the terminal infrastructure facilities required to support a fast passenger ship operation at the Port of Spain Ferry Terminal fuelled by LNG and including the supply of LNG to the port and bunkering of the ship.
Component 3/Chapter 4 Regulatory design requirements	Identify the design requirements for the proposed fast passenger ship under the international regulatory regime pertaining to the carriage and storage of LNG as a fuel for ships with a specific reference to its use and storage on a fast passenger ship operating to and from the Port of Spain Ferry Terminal.
Component 4/Chapter 5 Safety issues and risk assessment	Identify and appraise the potential risks for passengers, ship crew and terminal of using LNG as a fuel for a fast shipping operating to and from the Port of Spain Ferry Terminal.
Component 5/Chapter 6 Cost estimations for newbuildings, retrofit and LNG infrastructure	Identify costs, that can be used by the Port Authority of Trinidad and Tobago as part of a business case, including for ship construction and delivery, costs for provision of an LNG ship bunkering facility, crew training costs, costs for maintenance etc. This should include an appraisal of retrofitting ships to use LNG as a fuel for existing ships operating from the Port Authority of Trinidad and Tobago.
Component 6/Chapter 7 Reporting of results and recommendations	Submit a draft report four months after the start date of the project on or before 22 November 2013.

2
Current traffic and future requirements

2.1 Ports and marine infrastructure in Trinidad and Tobago

The main port for passenger ferry traffic is located in the capital, Port of Spain. The port is administrated by the Port Authority of Trinidad and Tobago (PATT), and accommodates the following two ferry terminals and ferry services:

- The Port of Spain ferry terminal – TTIT, Inter-island ferry services
- The Water taxi terminal – Water taxi services

PATT is organized under the Ministry of Transport, and along with Port of Spain, PATT is responsible for administering nine more ports and some small harbours in Trinidad and Tobago according to the table below.

Table 2 – *Ports in Trinidad and Tobago under administration of Port Authority of Trinidad and Tobago*

Location/name of port	Type of port	UN port code[1]
Port of Spain	Seaport	TT POS
Point-à-Pierre Harbour	Seaport	TT PTP
Port of Scarborough	Harbour	TT SCA
Port of Chaguaramas	Harbour	TT CHA
Port of Tembladora	Pier, Jetty or Wharf	TT TEM
Port of Brighton (La Brea)	Pier, Jetty or Wharf	TT LAB
Port of Cronstadt Island	Pier, Jetty or Wharf	
Crown point Harbour	Harbour	
Galeota Point Harbour	Harbour	TT PTG
Port of Point Fortin	Pier, Jetty or Wharf	TT PTF

[1] Code for Trade and Transport Locations (UN/LOCODE), ref (UNEC).

In addition to the PATT ports, there are also a number of important industrial ports in Trinidad and Tobago. The following three ports are interesting with respect to this study.

Point Lisas is the second largest port after Port of Spain and its administration is organized under the Ministry of Trade and Industry by the Point Lisas Industrial Port Development Corporation Ltd (PLIPDECO).

Pointe-à-Pierre is the main oil terminal used for transportation to and from the state-owned company, Petroleum Company of Trinidad and Tobago Ltd (PETROTRIN).

The Point Fortin LNG terminal is part of the Atlantic LNG Company of Trinidad and Tobago. The main owners of Atlantic are international energy majors but the government of Trinidad and Tobago holds, via its National Gas Company (NGC) and its subsidiary Trinidad and Tobago LNG Ltd, 11.11% equity in Atlantic LNG train No. 4. There is at present no port facility for small-scale export or for loading small LNG carriers or bunker vessels.

Table 3 – *Important industrial ports in Trinidad and Tobago*

Location/name of port	Type of port	UN port code
Port of Point Lisas	PLIPDECO	TT PTS
Pointe-à-Pierre oil terminal	PETROTRIN	TT PTP
Point Fortin LNG terminal	Atlantic LNG Company of Trinidad and Tobago	TT PTF

Figure 1: *Map of Trinidad and Tobago (CIA, 1969) with TTIT's ferry services Port of Spain – Scarborough (red) and NIDCO's water taxi*

2.2 Trinidad and Tobago inter-island ferry services, TTIT

The inter-island ferry services, operated by Trinidad and Tobago Inter-Island Transportation Company Ltd (TTIT), include passenger and car ferry services between the two sister islands. The TTIT fleet is operating from the Port of Spain ferry terminal to Scarborough in Tobago with two high speed vessels and one conventional ro-ro vessel.

There has been regular passenger traffic on the Trinidad–Tobago route from 1901. In the 1960s, ro-ro ferries were introduced. A first trial with high speed services was done in 1994, but it was not until 2005 that regular high speed ferry services took over the main part of the passenger traffic. Since 2007, the government of Trinidad and Tobago has owned, through PATT and TTIT, the two high speed ferries **T&T EXPRESS** and **T&T SPIRIT**, which are now in service on the route.

2.2.1 Present fleet of vessels

The Trinidad and Tobago Inter-Island Transportation Company Ltd is operating two high speed catamarans and one conventional ro-ro vessel:

- The **T&T SPIRIT** (Incat No. 060, 765 passengers/200 cars),
- The **T&T EXPRESS** (Incat No. 046, 840 passengers/200 cars), and
- A conventional ro-ro vessel (**WARRIOR SPIRIT**, 3314 dwt, built 1980).

The ro-ro vessel **WARRIOR SPIRIT** is complementing the high speed passenger services. Basic data of the high speed ferries are given in the sections below. Some data are also presented for the ro-ro vessel even though they are not of direct interest with regard to this LNG pilot study.

T&T SPIRIT

The High Speed Craft (HSC) named **T&T SPIRIT** was commissioned in July 2007. The vessel was originally designed for and operated by the US Army Tank-Automotive Command and was then reconstructed to service regular inter-island passenger traffic. Originally constructed in 2002 and just as the **T&T EXPRESS**, it is an aluminium wavepiercer catamaran by Incat with No. 060 and has main particulars according to the table below.

Table 4 – *Main particulars of the HSC* ***T&T SPIRIT***

T&T SPIRIT	Particulars	Comments
Year of build	2002	InCat Australia Pty Ltd, Moonah, Australia
Ship yard's Id	No. 060	
Length (overall), LOA	97.2 m (319 feet)	
Beam (overall), B	26.0 m (85 feet)	
Draft (loaded), T	3.43 m (11.2 feet)	
Displacement (light/loaded)	1056/1800 m^3	
Gross tonnage GT	6558	
Service speed	40 knots	
Total power	4 × 7080 kW	4 × Ruston 20RK270 Diesel engines
Gearbox reduction ratio	1:1.824	4 × RENK ASL 60
Waterjets	2 × 2 two in each hull	4 × LIPS, Type LJ145D
Auxiliary machinery, genset	4 × 265 kW	4 × Cummins N14
Capacity (crew + passengers)	900 persons	
Vehicle capacity	Approximately 200	380 lanemetres
Fuel capacity	190 m^3 (normal bunker)	2 × 210 m^3 (long range fuel tankage)
Classification society	DNV	

Figure 2: ***T&T SPIRIT*** *leaving Port of Spain for Tobago, November 2012*

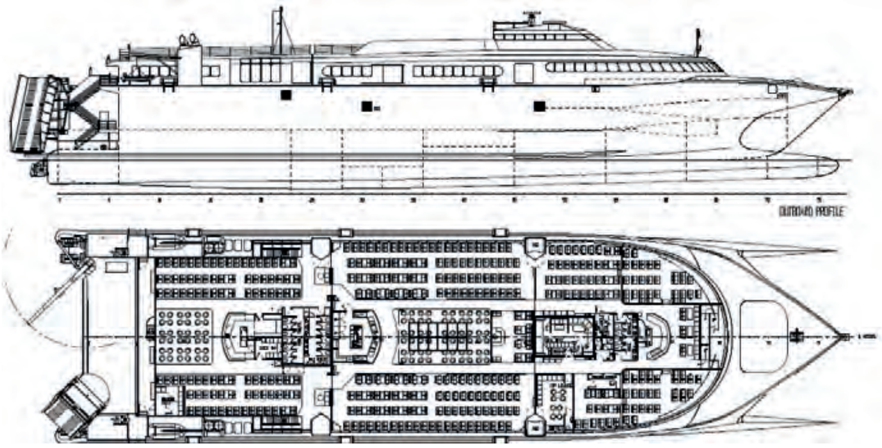

Figure 3*: **T&T SPIRIT**, general arrangement outboard side and passenger deck top view*

Figure 4: ***T&T SPIRIT** berthing with stern at car ramp and passenger ramp in Port of Spain ferry terminal*

T&T EXPRESS

The **T&T EXPRESS** was purchased to TTIT and put into service in December 2006. Before entering into service, it was refurbished after 10 years of operations in Australia, Nova Scotia, and the Bahamas. The government of Trinidad and Tobago owns the ship via PATT and the operator TTIT but the operational management and manning for **T&T EXPRESS** and **T&T SPIRIT** is performed by the Canadian company Bay Ferries on behalf of the owner. The vessel is an aluminium wavepiercer catamaran constructed by Incat with No. 046, and has main particulars according to the table below.

Table 5 – *Main particulars of the HSC T&T Express*

T&T EXPRESS	Particulars	Comments
Year of build	1997	InCat Australia Pty Ltd, Moonah, Australia
Ship yard's Id	No. 046	
Length (overall), LOA	91.3 m (300 feet)	
Beam (overall), B	26.0 m (85 feet)	
Draft (light/loaded), T	2.9/3.7 m (9.5/12.1 feet)	
Displacement (light/loaded)	900/1400 m^3	
Service speed	42 knots	
Gross tonnage GT	5617	
Total power	4 × 7080 kW	4 × Ruston RK270 Mk2 Turbo Diesels
Gearbox reduction ratio	1:1.824	4 × RENK ASL 60
Waterjets	2 × 2 two in each hull	4 × LIPS, Type LJ145D
Auxiliary machinery, genset	4 × 240 kW	4 × Caterpillar 3406B/3408
Capacity (crew + passengers)	873 persons	
Vehicle capacity	Up to 240	
Fuel capacity	4 × 14 m^3 integral alu tanks	2 × 170 m^3 (long range fuel tankage)
Classification society	DNV	

A general arrangement, outboard side and top view, is shown in the figure below.

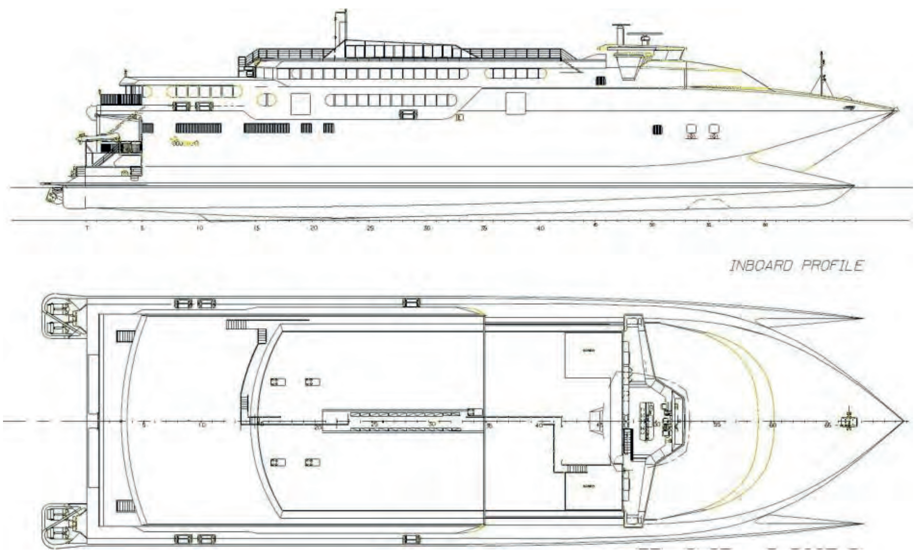

Figure 5: ***T&T EXPRESS***, *general arrangement outboard side and top view*

Figure 6: ***T&T EXPRESS*** *at berth in Scarborough, November 2013*

WARRIOR SPIRIT

The traditional ro-ro vessel **WARRIOR SPIRIT** is primarily used for transportation of cargo between the sister islands. Transportation of food, construction material and fuel from Trinidad to Tobago is regularly conducted by trucks carried on board the **WARRIOR SPIRIT**.

Table 6 – *Main particulars of the* ***WARRIOR SPIRIT***

WARRIOR SPIRIT	Particulars	Comments
Year of build	1980	Societe Nouvelle des Ateliers et Chantiers du Havre – Le Havre
Ship yard's Id	253	
Length (overall), LOA	126 m	
Beam (overall), B	21 m	
Draft, T	6.3 m	
Displacement (loaded/light)	8215/5556 m^3	
Service speed	17 knots	
Gross tonnage GT	11 457	
Total power	11 023 kW	
Auxiliary machinery, genset	unknown	
Capacity (crew + passengers)	48 cabins	105 berth + 96 driver berths
Classification society	Bureau Veritas	

Figure 7: ***WARRIOR SPIRIT*** *approaching the ferry terminal in Port of Spain*

2.2.2 Port infrastructure

Port of Spain ferry terminal

The Port of Spain ferry terminal is located south of the main deep water basin close to the city centre and is surrounded by busy streets and a ship repair yard in the north west and the CARICOM Wharf on the east side. The entrance from land to the ferry terminal is situated close to a busy street junction between South Quay, Beetham Highway and Wrightson Road and vehicles entering or leaving the ferry terminal often have to queue. The road and park areas inside the terminal area are limited, so queuing often delays the unloading of cars. Persons travelling with vehicles as well as passengers without cars are required to be at the ferry terminal two hours in advance of the scheduled departure time, and the check-in counter closes 30 minutes prior to departure.

In the sea chart in the figure below, the ship contour of a high speed vessel (red contour) is marked in the position of the ferry berth, and another contour (green) is marked at the roro-vessel berth.

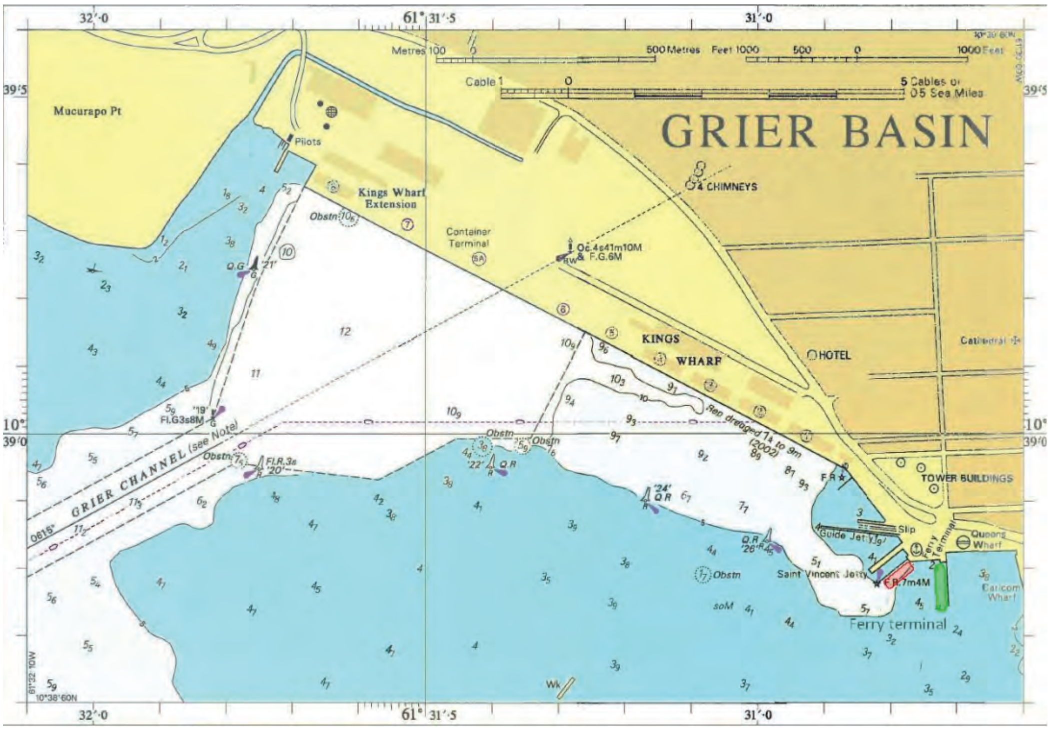

Figure 8: *Sea chart of the Port of Spain (Grier basin) showing the location of the TTIT ferry terminal with high speed ferry berth (the red contour represents* ***T&T SPIRIT****) and the ro-ro berth (the green contour representing* ***WARRIOR SPIRIT****) (Chart extracted from British Admiralty sea chart No. 474)*

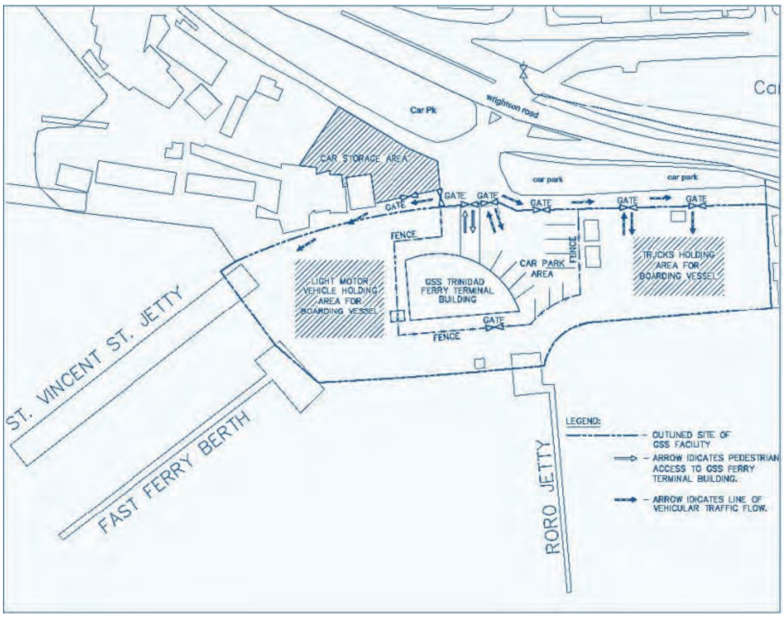

Figure 9: *Port of Spain Ferry terminal berth layout and vehicle traffic flows (PATT, 2013)*

Figure 10: *Port of Spain ferry terminal entrance from the city*

Figure 11: *Port of Spain ferry terminal with St Vincent jetty (left) and terminal building (centre)*

Scarborough ferry terminal

The figures below illustrate the ferry terminal in Scarborough. The layout is much more spacious than the ferry terminal in Port of Spain.

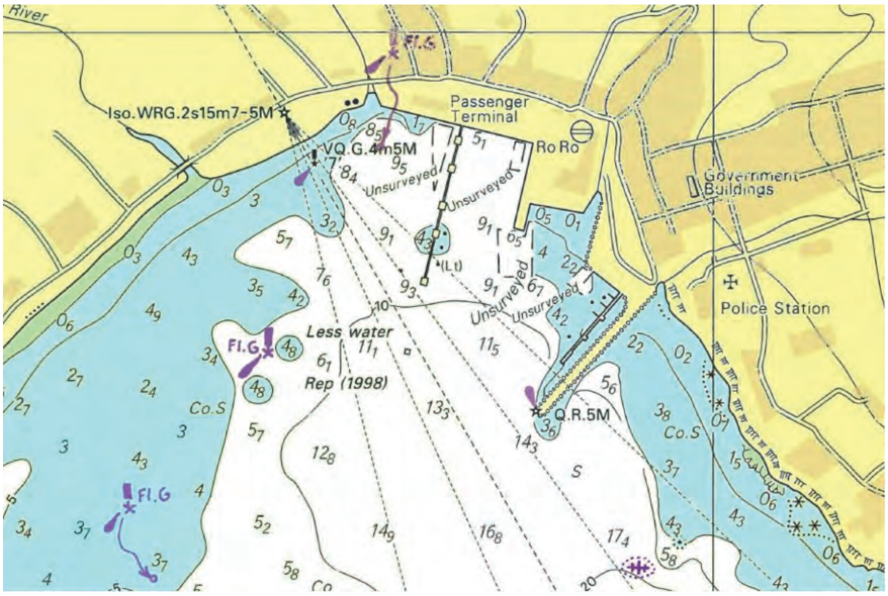

Figure 12: *Extract from the sea chart of the Port of Scarborough Tobago showing the location of the TTIT passenger terminal with high speed ferry berth (Chart extracted from British Admiralty sea chart No. 477)*

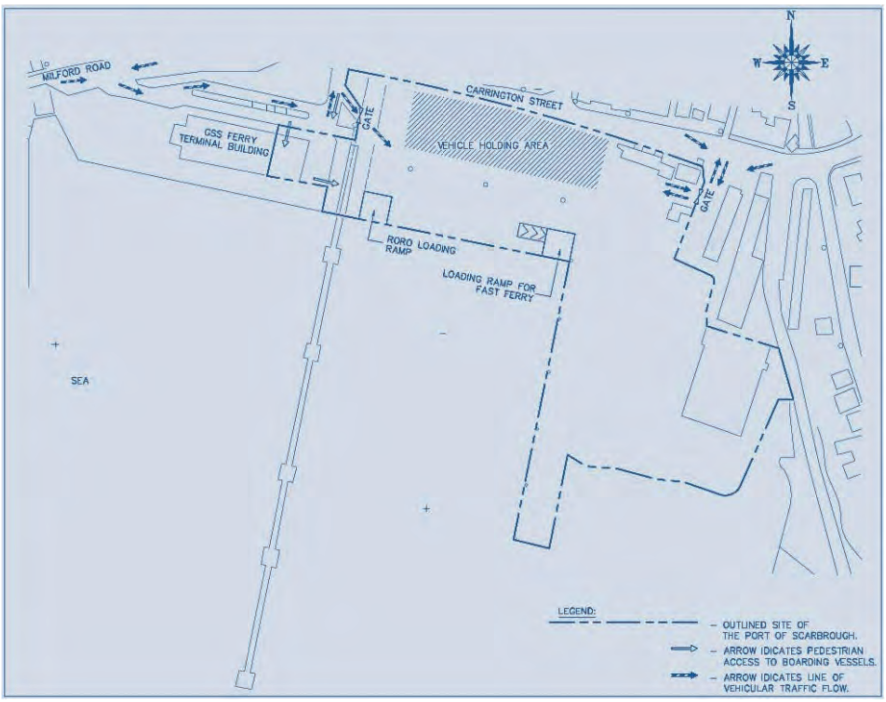

Figure 13: *Port of Scarborough berth layout (PATT, 2013)*

2.2.3 Route and schedule

The conventional ro-ro vessel makes one return trip per day, and each of the two high speed ferries normally makes one return trip and stays overnight in Port of Spain and Scarborough respectively. In the high season, on Fridays, and other occasions with many travellers, one of the vessels makes two return trips per day. With both the high speed vessels in service, it is possible to do two round trips per vessel during the daytime. Therefore, the system is very flexible, and allows for an increased capacity in peak periods.

The graph below shows a graphic example of the schedule for TTIT's three vessels, and the inclination of the lines corresponds to the vessels' speeds.

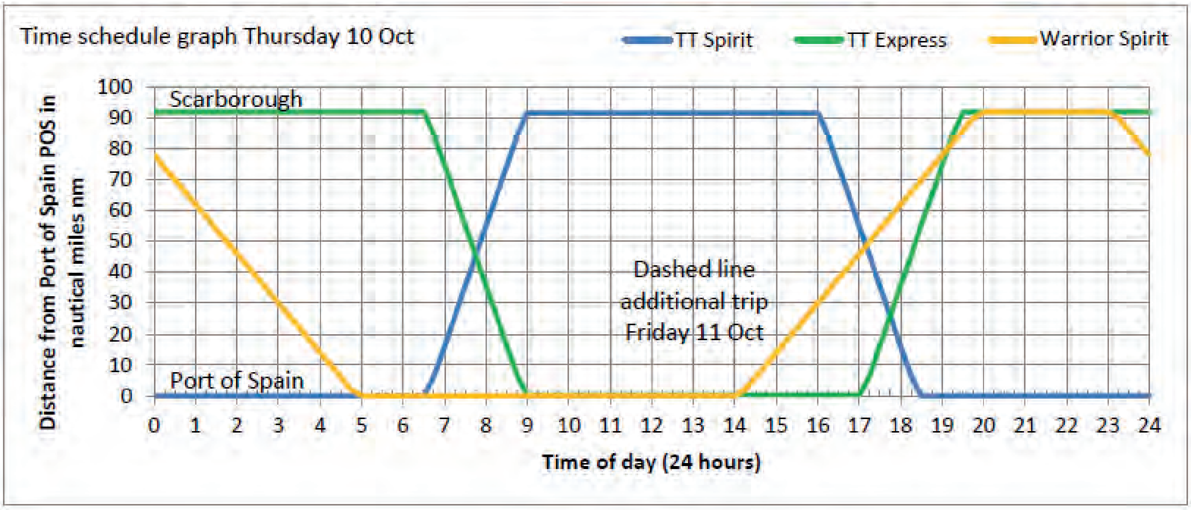

Figure 14: *Normal sailing schedule weekdays with two high speed vessels and one conventional ro-ro vessel. The distance from Port of Spain to Scarborough is 92 nautical miles and the speed is about 39 knots for a 2½ h trip. Example from 10–11 October 2013.*

Normal high speed services, with one return trip from each port can be maintained also with only one high speed ferry according to the graphical example below. This single high speed ferry schedule does not, however, allow for extra trips in the daytime and is sensitive in terms of reliability and disturbances.

The morning departure from Tobago at 06:30 and the afternoon departure from Port of Spain at 17:00 are not changed in the two schedules, indicating the importance of these daily tours in particular for people from Tobago visiting Port of Spain for a day trip.

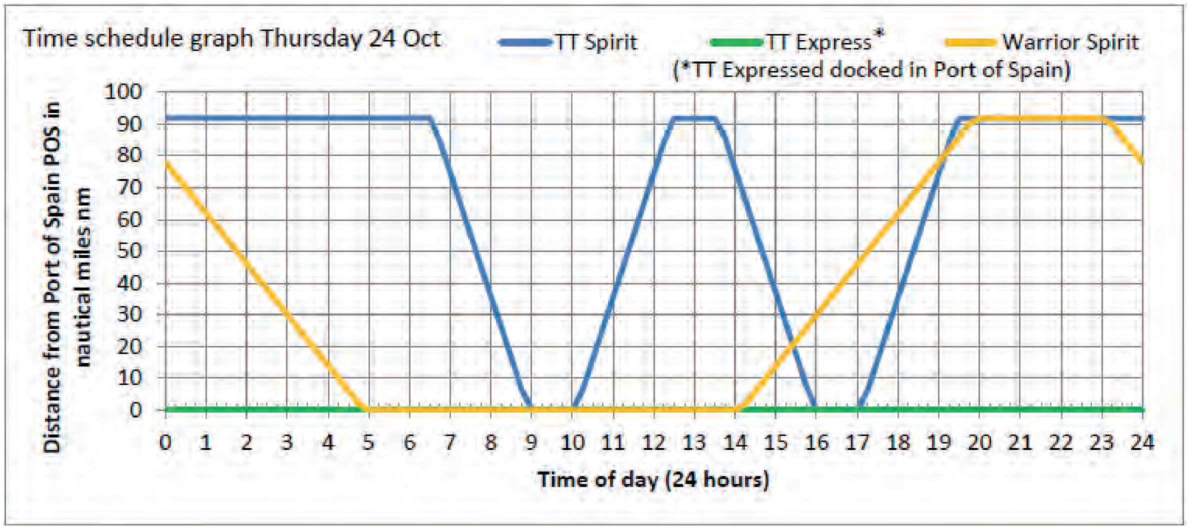

Figure 15: *Sailing schedule weekdays with only one high speed vessel and one conventional ro-ro vessel in operation. Example from 24 October 2013.*

2.2.4 Passenger statistics

The high speed ferry services are highly appreciated by the travellers. Since 2007, when the high speed ferries were introduced, the number of passengers has increased from about 400 000 per year to more than 1 000 000 per year today. There are no predictions available on future passenger development but it is generally anticipated that the number of travellers will continue to grow.

In 2012, the total number of passengers for the fleet of three vessels was 1 023 961 and the first seven months of 2013 indicate a slight increase compared with 2012 according to the graph in the figure below.

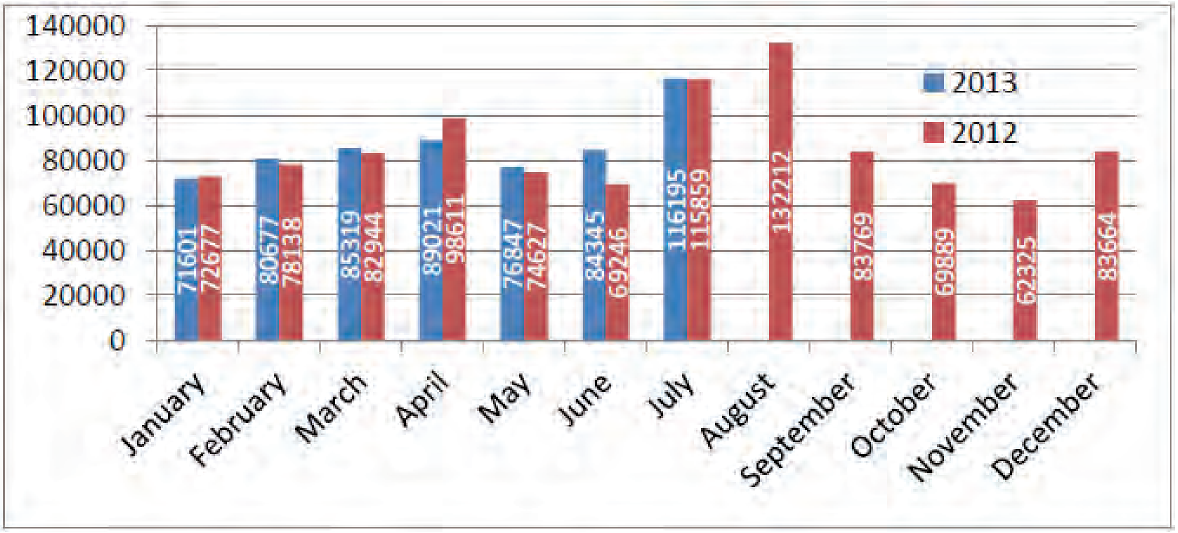

Figure 16: *Passenger statistics 2012 and 2013, passengers for all three ferries are summarized per month*

The week of Easter and the holiday season from July to August are the peak seasons in passenger traffic. Key features of the high speed ferry services that are particularly appreciated by the passengers are considered to be:

- Short travel times
- Low fares
- High frequency
- Reliability and regularity
- Comfort

Environmental performance may also be presented as an attractive feature for passengers and public opinion if LNG is introduced as fuel instead of MDO. The air quality in the terminals during departure and arrival as well as the atmosphere on open deck areas during transit will be significantly better because exhaust smell and visible smoke will be eliminated with LNG fuelled ferries.

2.3 Water taxi services operating from the Port of Spain water taxi terminal

2.3.1 Present fleet and terminals

Starting in 2008, the National Infrastructure Development Company Ltd (NIDCO) introduced the water taxi services as an alternative mode for passenger transportation with the objective to ease traffic congestion along major routes on land. Today the water taxi fleet comprises the four sister ships: Calypso Sprinter, Carnival Runner, Paria Bullet and Trini Flash. The water taxi terminal and base port is located at the south east end of the Kings Wharf in Port of Spain.

Figure 17: *The water taxi terminal in Port of Spain, entrance from the city to the left. The photo to the right shows the four vessels of the fleet berthed in San Fernando.*

Main particulars of NIDCO's water taxi vessels Calypso Sprinter, Carnival Runner, Paria Bullet, Trini Flash			
Length	41 m	Year of build	2010
Passenger capacity	405	Shipyard	Austal Group, Australia
Speed	37	Deadweight	40 tonnes

Figure 18: *Calypso Sprinter and Carnival Runner berthed in Port of Spain*

2.3.2 Routes and timetables

The water taxi services operate between Port of Spain and San Fernando on weekdays. On weekends, this service also includes additional trips between Port of Spain and Chaguaramas.

The weekday schedule includes three morning departures (06:00, 06:45, and 08:00) and one afternoon departure (16:30) from San Fernando to Port of Spain. In the opposite direction from Port of Spain, there is one morning departure (07:00) and three afternoon departures (15:30, 16:30 and 17.30) to San Fernando.

On the weekends, the schedule includes one morning departure from San Fernando (09:30) to Port of Spain and one afternoon departure from Port of Spain (06:30) to San Fernando. In addition, the ferries conduct three return trips between Port of Spain and Chaguaramas. Each single trip between Port of Spain and Chaguaramas takes 30 minutes and a total of two vessels conduct two 45-minute and six 30-minute trips per day on the weekends.

With the present time schedules, NIDCO's fleet of high speed ferries has the operational capacity to increase its services, and discussions are currently underway regarding new routes and additional ports of call in the Gulf of Paria. Possible future plans of diversification of the water taxi services also include the implementation of charters, tours and advertising opportunities.

2.3.3 Fuel consumption and possibilities for future use of LNG as ship fuel

In the present time schedule with two of the water taxi vessels in operation, the average fuel oil consumption is 3.56 tonnes per day per vessel.

The ships are relatively new and reconstruction for LNG fuel is presently not considered feasible. Moreover the engine supplier has no plans to offer conversion kits for the specific main engine types. Replacement of existing diesel engines and installing new dual fuel engines would imply difficulties with regard to weight and space. The owner, NIDCO, presently has no plans for acquiring new vessels and does not consider LNG retrofit installation attractive.

Nevertheless, LNG-fuelled water taxi vessels might offer an environmentally attractive alternative for the reduction of traffic and congestion problems on the road and on land in the long term, when the company replaces the vessels of the water taxi fleet.

2.4 Environmental performance and exhaust emissions

TTIT's present fleet of high speed ferries are operating with Marine Diesel Oil (MDO) as fuel. In contrast to Marine Gas Oil (MGO), which contains only distilled products, the MDO is a blend of distilled products and some residual fractions. MDO may have a sulphur content up to 2% but a typical value of about 1% sulphur is here assumed representative for comparative calculations of emissions from MDO and LNG fuelled high speed ferries.

2.4.1 Fuel oil consumption and emissions from current ferry services

The recorded consumption data (TTIT, 2013) of TTIT's current fleet of high-speed ferries and the typical general specific emission figures for the category of diesel engines installed in those ships were used to calculate the following rough estimations of annual emissions of characteristic exhaust gas components. The sulphur content of the MDO is assumed to be 1%.

Table 8 – *Annual quantities of exhaust gas components from TTIT's high speed ferries operated by MDO*

Fuel consumption tonnes of MDO/year	Emission of CO_2 tonnes per year	Emission of SO_x tonnes per year	Emission of NO_x tonnes per year	Emission of PM tonnes per year
19 300	61 500	771	1 160	21

2.4.2 Possible reduction of emissions by the introduction of LNG fuel

Based on the estimated consumption of LNG if TTIT's current fleet of high speed ferries would be reconstructed with LNG fuelled gas turbines as main engines and on typical general specific emission figures for LNG fuelled gas turbines, the following rough estimation of annual emissions of characteristic exhaust gas components has been calculated. It should be noted that the annual fuel consumption in terms of total energy content will increase when the diesel engines are replaced by gas turbines because of the lower rate of efficiency in gas turbines compared with diesel engines.

Table 9 – *Annual quantities of exhaust gas components from TTIT's high speed ferries operated by LNG*

Fuel consumption tonnes of LNG/year	Emission of CO_2 tonnes per year	Emission of SO_x tonnes per year	Emission of NO_x tonnes per year	Emission of PM tonnes per year
20 300	52 600	0	569	0

Comparisons between the two tables above reveal that the use of LNG as fuel for the high speed ferries will eliminate the emissions of sulphur oxide (SO_x) and virtually eliminate the emissions of particulate matter (PM). Furthermore, the emission of nitrogen oxide (NO_x) will be significantly reduced, but the indicated figure is considered conservative. Further NO_x reductions may be obtained if the gas turbine is equipped with water or steam injection. By installing of such devices, the annual NO_x emissions from the LNG fuelled gas turbines may be reduced to less than 200 tonnes.[1] Exhaust heat recovery and water or steam injection may also contribute to higher efficiency and lower specific consumption for the gas turbine installation.

Comparison of the carbon dioxide (CO_2) emissions indicates a reduction of about 15%, even though the efficiency rate is lower for the gas turbines than it is for the diesel engines.

[1] The NO_x emission figure in table 9 is based on a specific emission factor of 7 g/kWh but the specific emission of 1–2 g/kWh may be gained with water or steam injection (Siemens, 2008).

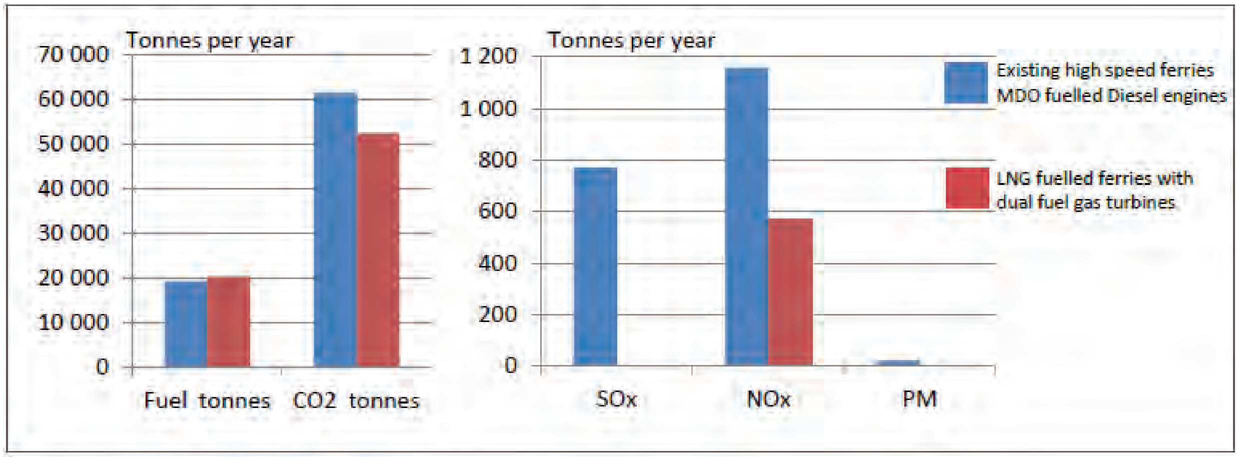

Figure 19: *Comparison of annual fuel consumption and emissions for a fleet of two high speed ferries powered by diesel engines and MDO and by gas turbines and LNG respectively*

From a local environmental and health perspective in Trinidad and Tobago, the reduction of the particulate matters, PM, is considered the most important factor of improvement by introducing LNG as fuel for the high speed ferries. Reduced concentrations of PM in the air in urban areas and cities that are exposed to heavy traffic, such as Port of Spain, can often be translated into figures of saved lives and averted fatalities.

Presently, no decision has been made to designate the waters where the TTIT high speed ferries are operating as an emission control area (ECA), so there will be no international compulsory requirements calling for reduced SO_x or NO_x emissions from the ferries in the near future. However, there are a number of new ECAs in force around the world, and more stringent emission requirements will come into effect in these from 2015. In the future, it is possible that the entire Caribbean Sea and WCR will become an ECA.

Reconstruction for LNG fuel operation or newbuilding will facilitate compliance with future ECA requirements and with diesel/LNG dual fuel systems installed, the attractiveness and value of the ships will be higher also in a secondhand market.

3

LNG supply chain and bunkering infrastructure

3.1 General requirements of a supply chain for LNG as marine fuel

There are several aspects to consider when designing a supply chain for LNG as marine fuel. Some important aspects are:

- Reliability
- Safety
- Security of supply
- Flexibility
- Capacity
- Operational cost
- Investment costs

Different stakeholders may prioritize these aspects differently but none of the aspects can be excluded.

From the shipowner's perspective, three aspects are predominant: the price of the fuel free on board (FOB), the reliability of the supply chain and the capacity of the supply chain in relation to the demand. If the LNG fuel price is much higher compared to other alternatives, then LNG is uncompetitive and will most likely not be selected as a fuel. In addition, if there are insufficient volumes of LNG and the bunkering vessel cannot bunker the required amount of fuel when needed, then consequences may be severe for LNG as a marine fuel.

Compared with traditional oil based ship fuels, the equipment and resources used in an LNG supply chain are more complex and more expensive, both in terms of CAPEX and OPEX, primarily due to the cryogenic temperatures of LNG. Therefore, the optimization of all relevant aspects is important to keeping down the costs without compromising safety and security.

Another important difference between LNG as marine fuel and the traditional, oil based ship fuels is that LNG has to be handled with care due to its perishable characteristics. The composition of LNG may change if it is handled incorrectly, making it less valuable or even useless as marine fuel. It may also generate negative environmental impact and pose significant risks to people when LNG vaporization creates high pressure.

3.2 Supply chains

Before the start-up meetings and workshop in September 2013, 28 possible supply chains were outlined by the consultant team as a starting point for the discussions. A graphical presentation of all the supply chains is presented in appendix 2. All supply chains were designed in line with the principal supply chain displayed in figure 20 below.

Figure 20: *Initial hypothesis of a supply chain of LNG as marine fuel to the high speed vessels in Port of Spain*

Due to the fact that Trinidad and Tobago accommodates one of the largest LNG production plants in the world with an annual capacity of approximately 15 mmpta of LNG, the Atlantic LNG facility in Point Fortin was considered the obvious choice for a LNG source for all supply chains. However, the workshop and meetings in September 2013 made clear that some limitations on the possibilities for using Atlantic LNG as the source of LNG exist. At present, domestic redistribution of LNG is outside the scope of the mandate of Atlantic LNG (Ramlakhan, 2013).

For this type of pilot study, it is important to establish feasible conditions for the source of the LNG supply at an early stage. Especially for studies addressing vessels with pure gas (non-dual fuel) engines, alternative sources of supply may also need to be considered to minimize risks and to secure a continuous supply of LNG fuel at favourable conditions.

Based on the initial information retrieved from the different stakeholders, two of the 28 identified supply chains were at an early stage of the project selected for further evaluation. Due to the sourcing issue mentioned above, an additional third supply chain was developed. All three supply chains are thoroughly described in sections 3.5 to 3.7.

3.3 Possible bunkering solutions

Just like the bunkering of traditional oil fuels, LNG bunkering may be performed in different ways. At present, most LNG bunkerings are made either from truck to ship or from small intermediate bunker terminals. During the development of the different supply chains as described in appendix 2 the following bunkering solutions were considered: truck to ship (TTS), intermediate tank via pipeline to ship (ITPS), ship to ship (STS), and container to ship (CTS).

3.3.1 Truck to ship (TTS)

The most common LNG bunkering method today is truck to ship. It is a feasible option as long as the volumes are reasonably small. A tank truck can carry up to approximately 22 tonnes of LNG depending on the capacity of the tank truck, national transport and vehicle regulations, road infrastructure and the standard of the roads to be used. If the receiving vessels require large quantities (>50 tonnes), then other bunkering methods are usually more suitable.

Figure 21: *Truck to ship bunkering (TTS) of LNG from two trailers in parallel (Photograph reproduced courtesy of Skangass AS)*

The largest benefits of TTS operations are a limited initial investment and that the necessary investments are possible to use also for other purposes, such as local energy distribution. This makes the TTS method a very good start-up solution for LNG bunkering.

The limited capacity of the truck is, however, the most obvious limitation in this bunkering solution. Another disadvantage is that TTS operations may have an impact on the possibilities of parallel operations, because the bunkering operation has to be carried out on the quayside of the vessel and thus might interfere with cargo and passenger handling.

Bunkering locations are not fully flexible, because the location has to be connected to a road that is suitable for the transportation of LNG from the source.

3.3.2 Intermediate tank via pipeline to ship (ITPS)

Another commonly used bunkering solution is bunkering by pipeline directly from an intermediate LNG tank. Depending on the requirements and logistical options, the size of such tanks may vary from as small as a few tonnes to more than 50 000 tonnes. The LNG can be supplied to the intermediary tank via truck, barge, ship, or local production directly from the gas grid depending on the required volumes, availability, etc. It may also be possible to use an import or export terminal as a direct source for ITPS bunkering.

Figure 22: *ITPS LNG bunkering (Photograph reproduced courtesy of Eidesvik)*

One limitation to this solution is that it is technically and operationally challenging to have long pipelines, which implies that the tank has to be located in the proximity of the berth where the bunkering operation shall be performed. It is, however, not always possible to do this since the available space in combination with safety requirements and other on-going activities in the port can induce restrictions. The ITPS method also has limitations in its flexibility, because the bunkering position is fixed. Therefore, the solution is most likely to be used for a port or berth with a stable and long-term demand for bunker delivery or used when a local LNG bunker demand coincides with other consumers, making it possible to co-use the necessary infrastructure.

3.3.3 Ship to Ship (STS)

Both TTS and ITPS have clear limitations regarding capacity and flexibility. To avoid these, a more feasible option for LNG bunkering is by ship-to-ship operation, similar to how most fuel oil is supplied to ships today. The solution is flexible when it comes to both capacity and location, and an LNG bunker vessel or barge can be used to bunker most kinds of vessels. STS also has disadvantages, because the initial investment in a bunker vessel is significant, and it may be difficult to find alternative assignments for the bunker vessel when the LNG bunker demand is limited.

If a barge is used, then it may either be self-propelled or un-propelled using one or several tugs when moving.

Figure 23: *A 2 800 m^3 LNG bunker vessel (Photograph reproduced courtesy of White Smoke Shipping)*

3.3.4 Container to ship (CTS)

A solution that is commonly discussed but not yet fully developed or in use is container-based solutions whereby special LNG fuel containers are used both for transportation from the LNG source as well as for fuel storage on board the LNG fuelled vessel. Designed in line with standard ISO containers, the supply chain may utilize an already existing distribution infrastructure.

Figure 24: *LNG fuel container (Photograph reproduced courtesy of Marine Service GmbH)*

A standard 40′ ISO container is able to handle approximately 17 tonnes of LNG (Marine Service GmbH, 2013).

The benefit of the solution is combined utilization with existing distribution systems for containers. The main drawbacks are the high cost and high weight per tonne of LNG as well as some ambiguities when it comes to the regulations for shipboard use as fuel.

3.4 Demand estimation for TTIT's high speed ferry services

If related directly to the total daily consumption of MDO, as presented in section 2.4.1 of the existing TTIT vessels, the LNG demand is estimated to be approximately 42 tonnes per day. This number is considered accurate if pure gas or dual fuel piston engines are used as main engines for two new vessels or the two converted vessels.

Due to weight and space issues of the presently available dual fuel and pure gas engines it is deemed necessary to use LNG fuelled gas turbines if converting the **T&T SPIRIT**. For the same reason it is most likely that any newbuild high speed ferry also will use gas turbines as main engines.

This has a significant impact on the fuel consumption, because the efficiency of gas turbines generally is lower than for piston engines. Due to this, the estimated daily consumption is increased to approximately 60 tonnes LNG per day, 30 tonnes per return trip.

Based on the present timetable (described in section 2.2.3) it has been assumed that each supply chain should be able to deliver 30 tonnes of LNG as bunker, twice a day, to the ferry terminal either in Port of Spain or in Scarborough.

It is also assumed that the vessels are of dual fuel type and that the minimum storage capacity of LNG on board is approximately 35 tonnes or approximately 81 m^3 LNG if the vessels shall be able to operate on LNG only. The estimated consumption is concluded in table 10.

Table 10 – *Estimated LNG consumption for two high speed ferries*

Ferry	Daily tonnes	Daily MMbtu	Weekly tonnes	Weekly MMbtu	Annually tonnes	Annually MMbtu
No. 1	30	1 400	210	9 800	11 000	514 000
No. 2	30	1 400	210	9 800	11 000	514 000
Total	**60**	**2 800**	**420**	**19 600**	**22 000**	**1 028 000**

Each vessel needs to be bunkered between each round trip implying that if both vessels are in operation one bunkering will take place at night and one during the day in the selected bunkering port. Based on the present timetable, more thoroughly described in section 2.2.3, the bunkering time slot in Port of Spain is between 10:00 and 16:00 (daytime) and 19:30 until 5:30 (night-time).

The bunkering time slot in Scarborough is between 10:00 and 15:00 (daytime) and from 20:30 until 5:30 (night-time).

When the ferries are operated in line with the normal time schedule, there are at least five hours to perform each bunkering operation. Five hours are considered more than enough independently of selected bunkering method. This also implies that there will be enough time to perform each bunkering operation without passengers on board and with no parallel cargo handling, which is considered preferable from a risk and safety perspective.

During irregular situations when only one ferry is in operation, the situation changes. The available bunkering time is then shorter, depending on scheduling, and may be less than one hour. In such cases bunkering during cargo operation and with passengers on board is a necessity. If not accepted by local authorities or feasible from a safety point of view, this may require that MDO is used as fuel during periods with only one vessel in operation.

In the following sections, the three identified supply chain options are discussed and outlined with respect to the actual demands of the TTIT fleet.

3.5 Supply chain 1 – Truck delivery

The first supply chain to be assessed is a fully truck based solution using LNG semi-trailers both for transporting LNG from the source to the ferry terminal as well as for the bunkering operation itself.

Figure 25: *Supply chain 1*

3.5.1 Source

As source of the supply chain, two possible locations are used. The first is Atlantic LNG in Point Fortin and the second is the possible new small/mid-scale production plant in La Brea which is under discussion (Hosein, 2013). If Atlantic LNG is to be used, their mandate has to be updated to allow distribution of LNG domestically.

3.5.2 Required equipage and staff

The main equipment required for this supply chain is a suitable number of semi-trailers. It has been difficult to establish the maximum capacity for an LNG semi-trailer operated on Trinidad and Tobago since a special permit procedure is required for all vehicles with a gross weight above 15 tonnes. Since no road based LNG transportation has been done on Trinidad and Tobago there is no prejudice available.

Therefore it has been assumed that the Trinidad and Tobago authorities will approve LNG trailers similar to what is used both on the US and European market implying that the maximum capacity of an LNG semi-trailer is 20–22 tonnes of LNG. The loading and discharging time of one semi-trailer is 1 hour.

Figure 26: *A typical European Truck/LNG Semi-trailer combination (Photograph reproduced courtesy of Skangass AS)*

In addition to these semi-trailers a number of towing trucks is needed. It is assumed that such towing trucks are possible to charter from local trucking companies.

At the LNG source a truck loading facility has to be established with the ability to fill an LNG semi-trailer tank in a safe and efficient way. Preferably it will be able to load the trailers with LNG close to atmospheric pressure and with a temperature close to −162°C.

Both loading of the truck and the bunkering operations will be operated by the truck driver with assistance from the staff at the LNG production plant during loading and from the crew of the vessel during bunkering.

3.5.3 Scheduling

Due to the highly congested traffic in the Port of Spain area, as well as the narrow and undeveloped road network south of San Fernando, it is presently very difficult to estimate the time for an LNG semi-trailer to be towed from the selected LNG source to the ferry terminal in Port of Spain.

Fortunately there is an on-going project to extend the present highway south of San Fernando all the way down to Point Fortin making the traffic situation much less challenging to evaluate. According to NIDCO (NIDCO, 2013) the highway is supposed to be completed in March 2015 and all presented scheduling is based on the new road being ready.

Figure 27: *The on-going road development project (Photograph reproduced courtesy of NIDCO)*

The following table concludes the estimated travel times between the two possible sources of LNG and the ferry terminal in Port of Spain.

Table 11 – *Estimated transit times from source to Port of Spain ferry terminal*

Route	Peak hours[1]	Off peak hours	Distance
Atlantic - POS Ferry terminal	3h	2h	85 km
La Brea - POS Ferry terminal	3h	2h	70 km

[1] Weekdays 06:00-10:00 and 14:00-19:30.

To supply the required 30 tonnes of LNG for each bunkering, two semi-trailers are required. As long as the ferries are operated in normal operation mode, with one bunkering at night and one bunkering during the day, the full supply chain requires only two semi-trailers.

The following timetable is suggested to be used during normal operation:

	Trailer 1		Trailer 2	
Activity	**Start hour**	**Activity time (h)**	**Start hour**	**Activity time (h)**
Loading	21:30	1	22:30	1
Transit	22:30	2	23:30	2
Bunkering	00:30	1	01:30	1
Transit	01:30	2	02:30	2
Waiting	03:30	4½	04:30	4½
Loading	09:00	1	10:00	1
Transit	10:00	2	11:00	2
Bunkering	12:00	1	13:00	1
Waiting	13:00	5½	14:00	4½
Transit	19:30	2	19:30	2
Waiting	–	–	21:30	1

The timetable is designed to avoid transit during rush hours as well as bunkering with passengers on board.

3.5.4 Other consideration

To open up for truck based distribution of LNG in Trinidad and Tobago will also make it possible to distribute LNG for other purposes. Even if Trinidad has a rather extensive pipeline system for natural gas it may be economically feasible to use truck distribution of LNG for remote consumers on Trinidad, or even on Tobago.

3.6 Supply chain 2 – Local production

The second supply chain is based on a local production and storage facility in the vicinity of the ferry terminal, connected directly to the natural gas grid. If it is possible to locate the facility in or close to the ferry terminal, bunkering could be done directly from the facility via pipeline (ITPS) as described schematically in figure 28.

Figure 28: *Supply chain 2a*

If it is not possible to locate the facility close to the ferry terminal it is suggested that LNG is to be transported from the facility to the ferry terminal by truck where the bunkering will be performed TTS. This version of the supply chain is described schematically in figure 29.

Figure 29: *Supply chain 2b*

An advantage of both the 2a and 2b supply chains is that local production and storage plant could be located both in the vicinity of the Port of Spain Ferry terminal but also in the vicinity of the Scarborough terminal adding the possibility to introduce LNG as a possible mode of energy distribution in Tobago.

3.6.1 Source

The supply chain needs to be fed from any pipeline with available capacity. The daily consumption of natural gas is estimated to be approximately 84 000 m^3/day or 3.0 mmcfd.

At present such pipelines are available close to the ferry terminal in Port of Spain. A main 16″ feeder pipe of natural gas is connected to the power plant operated by The Power Generation Company of Trinidad and Tobago passing not far from the ferry terminal itself.

Due to the on-going activities at the power plant it could be a suitable location for either a small-scale LNG production and storage facility or the connection of a dedicated feeder pipeline, supplying the facility located at the ferry terminal. From the power generation plant it is about 1 200 metres to the ferry terminal.

In Tobago a suitable connection point is the Cove eco-industrial estate located at the Tobago gas pipeline receiving plant in the Lowlands. The distance from the estate to the Scarborough ferry terminal is approximately 7 500 metres. The Cove eco-industrial estate is also considered as a suitable place for a local production and storage facility.

Figure 30: *Tobago pipeline gas receiving plant in Cove eco-industrial estate, Tobago*

3.6.2 Required equipage and staff

The local production and storage facility has to be able to produce approximately 60 to 70 tonnes of LNG per day. There are a number of different suppliers and solutions available at the market. According to Galileo (Gandulfo, 2013) their Cryobox™ solution operates autonomously with no need to be continuously manned. It is however assumed that a supervision and maintenance organization related to the production and storage facility has to be available.

A suitable size of storage capacity is estimated to 145 to 165 m^3 which is equal to the estimated consumption of two ferries per day.

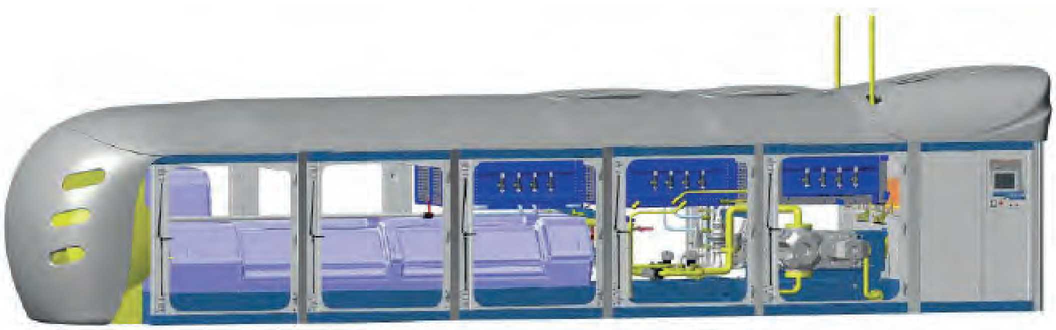

Figure 31: *The Cryobox™, an autonomous small-scale LNG production unit (Illustration reproduced courtesy of Galileo)*

Supply chain 2a requires an additional pipeline from a suitable connection point to the ferry terminal. It is estimated that such pipeline needs to be 1 200 metres if the local production and bunkering shall take place in the Port of Spain ferry Terminal. If Tobago is selected, the pipeline is estimated to 7 500 metres. The production and storage facility also needs to be equipped with a bunkering station similar to the one shown in figure 22 on page 34.

During bunkering the bunkering facility is required to be manned with a dedicated shore based person or by the crew from the ferry itself.

For supply chain 2b the local production and storage facility needs to be located close to a connection of the main pipeline and it needs to be equipped with a truck loading facility. The LNG supply from the facility will then be done by the same type of LNG semi-trailers as per supply chain 1. It is assumed that independently of selected location, the requirement of trucking is limited to only one LNG semi-trailer which has to be reloaded twice for each bunkering operation. Both loading of the truck and bunkering will be operated by the truck driver with assistance from the crew of the ferry during bunkering.

3.6.3 Scheduling

For supply chain 2a the requirements of scheduling is limited. The vessel may bunker when suitable. The bunkering time is estimated to 1 hour.

For supply chain 2b the bunkering time is still rather flexible as long as the distance from the local production and storage facility is limited. The required time for bunkering is considerably longer though since the LNG semi-trailer needs to be reloaded once during each bunkering operation. Therefore it is estimated that each bunkering will take approximately 4 hours: 2 hours is spent on bunkering, 1 hour of reloading and 1 hour is allocated for transit between the local production and storage facility and the ferry terminal.

3.6.4 Other consideration

As stated above this is the only one of the three described supply chain options that may be located in Tobago. The benefit of a Tobago located solution is that LNG may be distributed locally in Tobago supplying natural gas as energy to different consumers in Tobago without the investments in a gas grid on the island.

3.7 Supply chain 3 – Bunker barge

The third supply chain is based on an un-propelled barge with dual purposes. The barge is used both to source LNG and as bunkering vessels doing ship-to-ship bunkering in Port of Spain.

Figure 32: *Supply chain 3*

3.7.1 Source

As source of this supply chain two possible locations are used. The first is Atlantic LNG in Point Fortin and the second is the possible new small/mid-scale production plant in La Brea currently under discussion. For all scheduling purposes Atlantic LNG will be used as reference.

3.7.2 Required equipage and staff

A suitable capacity of the barge is 1 500 m^3 of LNG, corresponding to approximately 600 tonnes of LNG. The size of the barge will be approximately 50 × 22 metres with shallow draft. The barge will be equipped with two LNG tanks of 750 m^3 and with its own power production plant to provide power to cargo pumps, a bow thruster and miscellaneous systems.

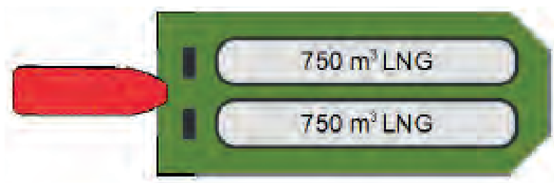

Figure 33: *Sketch of a 1 500 m^3 LNG barge connected to a harbour tug*

The barge will be moved by a standard harbour tug available in the area. When connected to the barge the service speed is estimated to 7 knots in normal weather conditions. Since the barge has a bow thruster it is assumed that the tug/barge unit will have enough manoeuvrability to do efficient bunkering operation in the Port of Spain Ferry terminal. It is assumed that the local authorities will not require any special certificates for the crew of the tug in relation to the LNG transportation and bunkering.

The barge itself needs to be manned with a cargo master responsible for all loading and bunkering operation. It is assumed that the local authorities only require his/her presence during cargo operations and that they accept that the barge is unmanned when moored in Port of Spain or during transit. If not, the OPEX cost of the barge will increase.

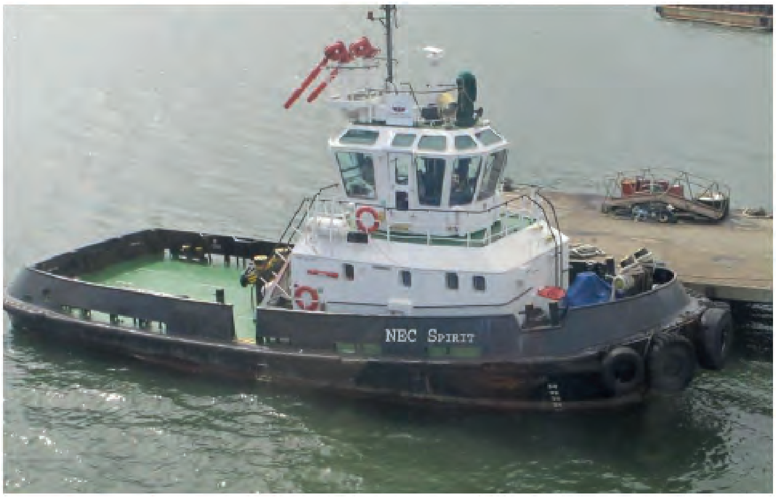

Figure 34: *Typical harbour tug used in the Bay of Paria area*

At the LNG source a small-scale jetty is required for loading of LNG. The jetty only needs to be approximately 70 metres long and with a minimum draft of approximately 3 metres.

3.7.3 Scheduling

By sea the distance between Port of Spain and Atlantic LNG is approximately 30 nautical miles. With a speed of 7 knots and some spare time for manoeuvring, etc. it is assumed that a trip in either direction takes approximately 5 hours.

With a daily consumption of 60 tonnes the barge needs to be refilled at the source every 10th day. Depending on both the design of the loading facility at the source and the design of the loading system and tanks on the barge, the loading time may differ. It is assumed that 5 hours is a reasonable loading time implying that a round trip with loading at source will take approximately 15 hours. As long as the high speed ferries follow normal operation there is enough time to do the reloading trip without missing a bunkering occasion.

A tentative schedule for a barge based LNG fuel supply chain is outlined in the table below.

	Day 1–9	**Day 10**
Connecting tug barge in Port of Spain	03:30	–
Start bunkering	04:30	04:30
Stop bunkering	05:30	05:30
Waiting	4½ h	4½ h
Start bunkering	10:00	10:00
Stop bunkering	11:00	11:00
Disconnecting barge	12:00	–
Transit to Atlantic LNG	–	5 h
Start loading	–	16:00
Stop loading	–	21:00
Transit to Port of Spain	–	5 h
Waiting	–	2½ h
Start bunkering	–	04:30

Based on the schedule above the tug is needed 12 hours per day during day 1–9 and 24 hours during day 10.

3.7.4 Other consideration

The main benefit of supply chain 3 is that it also offers the possibility to serve other vessels visiting the Bay of Paria area with LNG as marine fuel. At present the demand is non-existing but this may change rapidly if the foreseen international development concerning LNG as marine fuel commences in line with expectations.

4

Regulatory design requirements

4.1 Regulatory gaps and development of new frameworks

The development of LNG as marine fuel is still in its early stage and the availability of internationally accepted and ratified rules and regulations for the design and operation of LNG fuelled vessels as well as LNG bunkering facilities is limited. In addition to this the availability of nationally applicable rules, guidelines and standards for small-scale handling and transportation of LNG in Trinidad and Tobago is incomplete due to the fact that LNG has never been handled outside the premises of Atlantic LNG.

This chapter primarily includes selected examples and descriptions of rules, regulations, guidelines and standards that are recommended for application and may facilitate development of both the LNG fuelled high speed vessels as well as the supply chain of LNG as marine fuel.

Due to the unclear regulatory situation it is important to understand that any project has to be developed in close cooperation between the different stakeholders and authorities, and that a consensus of the selection and application of suitable rules and regulations has to be reached as early as possible in the process.

In the safety assessment presented in chapter 5 it is presumed that each element of the LNG bunkering chain is designed and operated in line with relevant rules, regulations, guidelines or standards as mentioned in this chapter. The same presumption applies to the cost estimations presented in chapter 6.

4.2 High speed vessels

At present there are no internationally applicable rules for the design of LNG fuelled vessels in general nor for LNG fuelled high speed vessels. This implies that it is up to the maritime competent authority of Trinidad and Tobago to decide which rules to apply for a conversion of the existing vessel as well as for a newbuilding as long as the new or converted vessels fly the flag of Trinidad and Tobago. If not flying the flag of Trinidad and Tobago the decision of applicable rules and regulations will be done by the selected flag State but the flag State of Trinidad and Tobago will have to consider the conditions carefully as the vessel will be operated domestically in Trinidad and Tobago.

The sections below summarize some of present rules and guidelines applicable for high speed vessels and that in combination may constitute a set of relevant rules and regulations for the design of LNG fuelled high speed vessels within the next few years. The regulations may be applicable regardless if the pilot project results in newbuilding or conversion of existing vessels. Some information is also included on future regulations under development and their expected finalization dates.

4.2.1 Resolution MSC.285(86)

Based on the rules and regulations developed in Norway primarily by the Norwegian Maritime Authority and DNV during the early 2000s, IMO in June 2009 adopted resolution MSC.285(86), also known as the Interim IGF guidelines. The document includes design criteria as well as operational and educational rules and regulations for LNG fuelled vessels. The document is only published as guidelines and is put in force by the IMO member States and therefore does not constitute an official IMO code. Nevertheless it is in principle applied on all LNG fuelled vessels in operation or under construction today.

4.2.2 Class rules

All major classification societies have their own rules concerning the design of LNG fuelled vessels. In principle all of them are based on the IMO resolution MSC.285(86) but there are differences in the interpretation and application.

Today DNV is the classification society which has classified the most LNG fuelled vessels but also GL, ABS and Lloyd's Register have LNG fuelled vessels in their class.

4.2.3 The forthcoming IGF code

Following the adoption of resolution MSC.285(86) in 2009, IMO has together with its member States worked with the development of the first fully applicable code for LNG fuelled vessels, the IGF code. When ready, it will become an amendment to SOLAS. Originally it was intended to be amended to SOLAS in 2013 then entering into force during 2015 but for various reasons it is delayed. At present the most plausible timetable indicates that the code will be amended into SOLAS during 2015 and if accepted by all parties entering into force at the earliest during 2017 (Hughes, 2013) (Safety4Sea, 2013).

As soon as it has entered into force it is compulsory for all vessels built (keel laid) or undergoing a major conversion after the date that the amendment entered into force and flying a flag of a contracting party of the SOLAS Convention.

4.2.4 International Code of Safety for High-Speed Craft, HSC Code

During the high speed vessel boom in the 1990s, the need for a code specifically addressing light high speed vessels was highlighted. This resulted in the development and introduction of the IMO International Code of Safety for High-Speed Craft, 1994 (1994 HSC Code) (resolution MSC.36(63)). A new version of the code was adopted in 2000, IMO International Code of Safety for High-Speed Craft, 2000 (2000 HSC Code) with the latest amendments now called the IMO International Code of Safety for High-Speed Craft 2000, 2008 edition.

For the **T&T SPIRIT** built in 2002 it is the 2000 HSC Code that applies.

4.2.5 Education of crew

At present the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, also known as the STCW Convention, does not include any requirements for education and training of crew on LNG fuelled vessels (STCW, 2011). The process to include such regulation is on-going but it is still unclear when relevant requirements will be amended and put in to force. Until then it is up to each flag State to decide how the crew on LNG fuelled vessels flying their flag is to be trained and educated (Hughes, 2013).

Chapter 8 of resolution MSC.285(86) specifies the basics of the educational requirements of the crew on board an LNG fuelled vessel. In addition DNV has published a document called "Competence Related to the On Board Use" (DNV, 2013). These two documents are considered a suitable framework for the elaborate educational requirements for high speed LNG fuelled vessels operating between Trinidad and Tobago.

4.2.6 HSC FRANCISCO

The only LNG fuelled high speed vessel in operation today is the Buquebus' operated **FRANCISCO** delivered by Incat in August 2013. It is operated between Buenos Aires in Argentina and Montevideo in Uruguay. Classified by DNV flying the Uruguayan flag it is an important reference for any development of LNG fuelled high speed vessels independently if the vessel is new build or converted.

According to DNV (Allwood, 2013) the vessel was issued with certificate of equivalence to the HSC requirement of carrying fuels with flash point below 35°C; this equivalence was based on compliance with resolution 285(86). According to DNV there were some significant challenges due to the fact that resolution 285(86) includes a number of demands not suitable for high speed vessels as well as the fact that gas turbines are not included in the resolution.

Therefore the overall compliance was achieved by use of safety cases, FMEA, and compliance with resolution 285(86) (IMO, 2009).

4.2.7 Defining applicable design requirements for LNG fuelled HSC

There are no specific rules for LNG fuelled vessels in general nor for LNG fuelled high speed vessels in particular. Conversion of an existing vessel or a newbuild therefore requires special considerations. The key to success is cooperation between the different stakeholders and authorities related to the project.

From a regulatory perspective the Maritime Service Division of Trinidad and Tobago has the overall responsibility to approve the design and operation of such a vessel. Another important key stakeholder is the selected classification society whose knowledge and expertise ensure a solid background information of the formal decisions made by the flag State.

Other important stakeholders may include the companies and organizations involved in the supply chain of fuel, the shipowner and ship operator, emergency response organizations, road administration, police, rescue services authorities, planning and building authorities, equipment suppliers, the selected yard, designers, etc.

4.3 Bunkering and local distribution facilities

The newly established Society for Gas as a Marine Fuel (SGMF) has published a document called Standards and Guidelines for Natural Gas Fuelled Ship Projects (SGMF, 2013). The document includes a useful review of relevant codes, rules, guidelines, etc. to be applied for various links of the supply chain of LNG as marine fuel.

For each of the three suggested supply chains described in chapter 3, a number of different equipage are needed to be able to supply LNG to the vessels. Relevant rules and regulations are summarized in the above mentioned document for most types of useful equipment.

Another useful document is the DNV GL recently published Recommended Practice (RP) document for authorities, LNG bunker suppliers and ship operators with guidance on development and operation of liquefied natural gas bunkering facilities (Lie Strom, 2013). It summarizes DNV's recommendations on how to establish a supply chain of LNG as marine fuel.

More general information is also provided in the book *An introduction to LNG bunkering* (Nigel, 2013).

4.3.1 Trucks

The main code regulating road traffic in Trinidad and Tobago is the Motor vehicles and road traffic act (Act). It regulates all types of vehicle with a maximum gross weight of less than 15 tonnes. All other vehicles are defined as special vehicles and require special permit. The permit is issued by the Ministry of Transport (Jones, 2013).

At present there are no general regulations available for road based LNG transportation on Trinidad and Tobago. Traditionally Trinidad and Tobago have used American rules and regulations for new application on shore (Tulsie, 2013). In this case the most adequate rules to apply are the CFR 49 which regulates both design and operation of LNG trucks and semi-trailers (CFR49). Another possible legal framework to consider for application is the European ADR regulation published by UNECE (UNECE, 2013) with a similar scope as the CFR 49.

4.3.2 Other LNG bunkering modes and operations

For the design of intermediate LNG terminals and for bunker barges as well as for LNG bunkering operations a summary of relevant regulations and guidelines may be found in the document, Standards and Guidelines for Natural Gas Fuelled Ship Projects published by Society for Gas as a Marine Fuel, SGMF (SGMF, 2013).

5
Safety issues and risk assessment

5.1 Risk assessment methodology for LNG bunkering of ferries

There are already more than 83 LNG fuelled vessels[2] in operation or on order worldwide, and a rapid increase is anticipated for the next decade (DNV, 2013). Different types of LNG supply chain are in use, but there are not yet established standards for LNG bunkering installations and procedures; however, standardization and harmonization are important for the expansion of the LNG fuelled fleet. A number of guidelines and recommended practices have been presented by ISO and other recognized organizations and indicate the direction of future standards and regulations that are now under development and being processed for international adoption.

The risk assessment methodology applied in this study is in part based on established general safety assessment methodologies outlined by IMO (IMO, 2007) and ISO (IEC/ISO, 2009), as well as on the new guidelines particularly addressing installation and operation of LNG bunkering facilities presented by OGP (OGP, 2013), ISO (ISO, 2013) and DNV-GL (DNV-GL, 2013).

No national regulations or established practices for the accomplishment of safety assessment, applicable specifically for LNG bunkering facilities, have been identified in the Trinidad and Tobago regulative framework.

At this stage of the pilot study, including optional LNG supply chains as well as newbuilding and retrofit options, qualitative and comparative risk aspects have been specifically addressed and considered in the recommendations and output of this study. For later design and engineering phases, more detailed risk assessments will need to be conducted in order to specify and verify that adequate safety levels have been met.

The figure below schematically illustrates how the presented optional LNG supply chains have been compared from a safety perspective including hazards due to interactions with the surroundings and LNG transfer interfaces in the supply chain associated with potential release of LNG.

Leakages, unwanted release of LNG and other hazards in the supply chain of LNG as fuel for ships may occur during the transfer of LNG from one transportation mode to another or from a tank to the ship. The focus of the study is, therefore, directed to such interfaces. A number of critical interfaces associated with release and fire hazards have been identified and described, and exemplify how these hazards can be quantified in terms of accident probabilities and consequences. The output of the risk assessment process includes recommendations to ensure adequate risk control primarily directed towards the prevention of LNG release and control of ignition sources.

[2] Excluding LNG carriers and inland waterway vessels, October 2013.

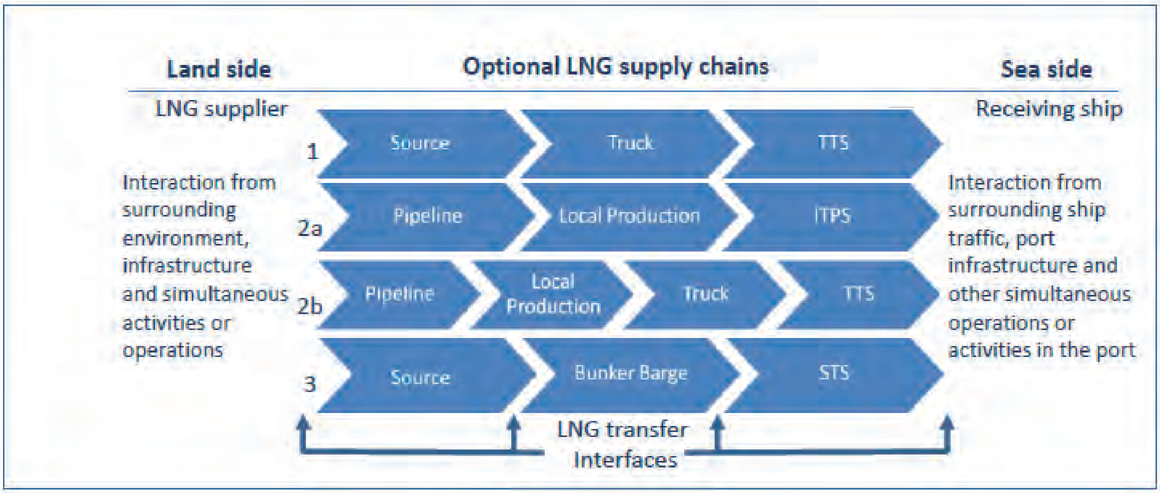

Figure 35: *Comparative risk assessment of the presented optional LNG supply chains with respect to hazards due to interactions with the surroundings and the LNG transfer interfaces associated with potential release of LNG*

The structure of the risk assessment process includes basic components according to the figure below.

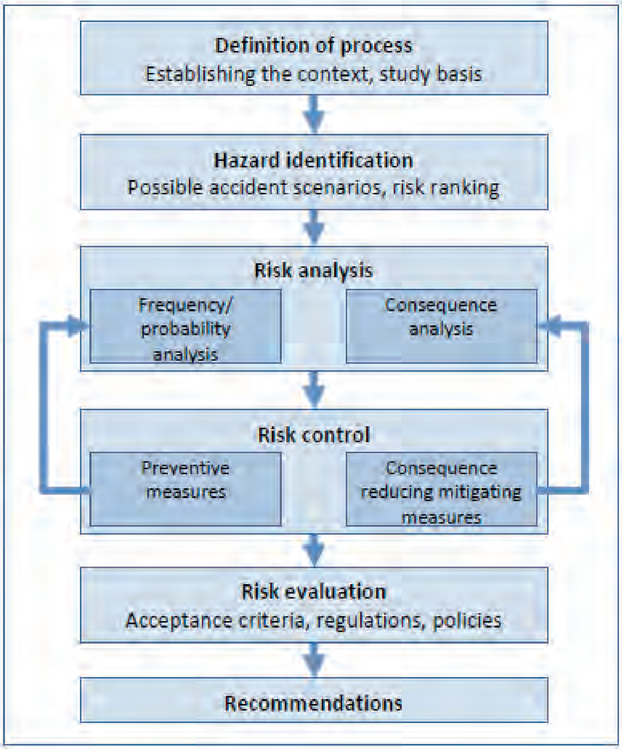

Figure 36: *General structure of risk assessment approach*

One of the primary output results for the risk assessment of an LNG bunkering system and facility is the establishment of adequate safety zones for LNG bunkering operations. The safety zone is the area around the bunkering station on the receiving vessel where only dedicated and essential personnel and activities are allowed during bunkering. Corresponding safety zones may also need to be established for other LNG transfer interfaces of the LNG supply chain, and it may also be relevant to establish additional exclusion zones outside the safety zone where other categories and third parties must not have access. In addition to the safety zone around the bunkering site, it may also be necessary to establish a security zone around the bunkering facility and vessel where ship traffic and other activities are monitored.

The site selection for bunkering operations and bunkering facilities as well as possible intermediate storage tanks also require careful zoning and consideration of risk distances to other activities and areas with public access, roads and residential areas.

Zoning considerations and classifications are also important with regard to type and location of electrical installations at the bunkering facility and standards such as the IEC EN 60079 (IEC, 60079) and corresponding national standards.

The draft guidelines from OGP (OGP, 2013) suggest two different approaches for conducting the risk assessment. These recommendations depend on the characteristics and complexity of the bunkering system and facility. For the non-complex base case, a set of 24 functional requirements, based on internationally recognized standards and good engineering practices, is formulated. If these 24 functional requirements are met and if there is no cargo handling conducted in parallel with the bunkering and no passengers on board the receiving vessel during bunkering operation, a qualitative risk assessment may be sufficient.

If the bunkering concept deviates from the non-complex base case or if all 24 functional requirements have not been met or if cargo handling is conducted in parallel, a more comprehensive quantitative risk assessment (QRA) approach should be undertaken. If passengers will be present on board the receiving vessel during LNG bunkering, acceptance from national competent authorities and all other stakeholders is also required.

There are two options for defining the design release scenario of adequate safety designs. The first and simplest way is the deterministic approach, where a conservative maximum credible accidental release is defined on the basis of the characteristics of the bunkering system. This option takes into account such factors as hose dimension, flow rate, pressure, temperature and ESD design. The second, and more sophisticated way, is to apply a probabilistic approach, where the cumulative consequences of a number of possible different leakage scenarios are summarized, e.g. by the use of an event tree model.

If a quantitative risk assessment (QRA) approach needs to be applied, the zoning considerations and definitions of safety zones are normally based on probabilistic approaches including detailed LNG dispersion, vapour cloud modelling and fire calculations for derivation of heat radiation risk contours around the bunkering site.

5.2 Experience of risks and risk control for LNG bunkering

A number of LNG fuelled passenger vessels are in operation today, most of them in Norway. A lot of experience has been gained from the operation of these ferries representing different ship sizes, engine types and bunkering concepts. A number of examples and experience from LNG fuelled ferries are described in appendix 3.

5.2.1 Safety records from LNG bunkering operations

LNG bunkering to ships is relatively new, and available accident records cannot be used to derive accurate accident statistics and probability figures. Most experience from small-scale LNG loading and unloading operations by use of trucks and flexible hoses comes from Norway, where more than 50 000 operations have been conducted without any serious accidents or significant releases recorded (Gasnor, 2012). In Norway through June 2012 only two minor LNG releases and onshore spills have been reported during ship bunkering. These where due to leakages from a valve and a hose resulting in a spill of approximately 1 litre.

Twelve years of accident statistics for road transportation of LNG for other industrial purposes in Norway include one case of hose leakage (2 litres) during truck loading. Two cases of ditching/crashes with LNG trucks have also been recorded, but without any LNG spills, further the LNG trailers were recovered (Karlsen, 2012).

5.3 Environmental and climatological conditions

LNG bunkering safety assessment has been conducted for a number of different locations, ports and ship services, but it is always important to adapt to and take into account the local specific conditions. Some main characteristics of the local environmental and climatological conditions considered in the risk assessment for the presented LNG supply chain options and bunkering arrangements are described below.

5.3.1 Prevailing wind conditions

The prevailing wind direction is easterly. The windrose in the figure below indicates that about 85% of the daytime observations in Port of Spain show wind directions between north east and south east. The statistics are based on observations recorded between February 2004 and September 2013 daily from 7 to 19 local time. Corresponding wind speed observations show monthly average values between 4 to 6 m/s (6 to 12 knots) (Windfinder, 2013).

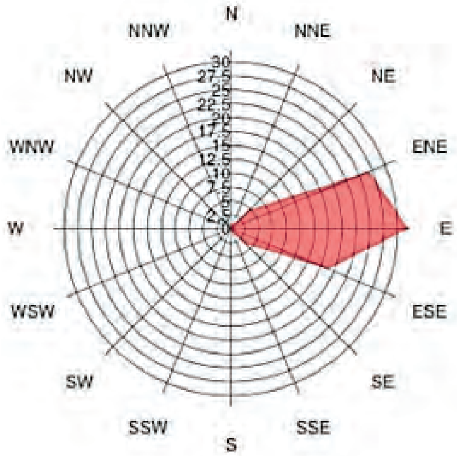

Figure 37: *Windrose Port of Spain, distribution of wind directions (Windfinder, 2013)*

5.3.2 Prevailing sea conditions

Due to the predominant easterly winds, the wave conditions in the Gulf of Paria and the waters around Port of Spain are calm. For the route from Trinidad to Tobago and the sea conditions outside Scarborough, wave statistics for the Caribbean Sea may provide reasonably representative figures. The diagram below shows the distribution of significant wave height over time. It indicates that the wave height is below 2 m about 50% of the time and higher than 2 m for 50%. Significant wave heights above 6 m are very rare, occurring less than 0.5% of the time.

It can be noted that no high speed ferry departure has been cancelled due to excessive wave heights or extreme wind conditions in recent years.

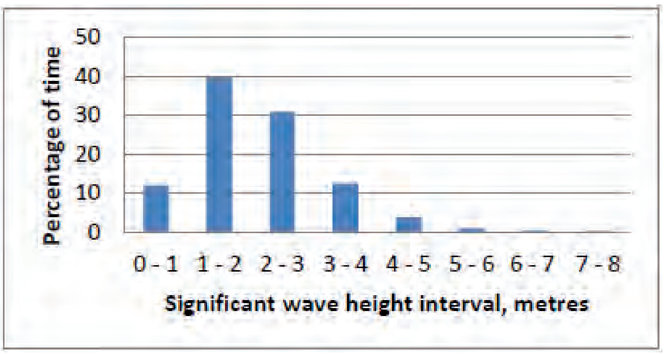

Figure 38: *Statistics on observed significant wave heights in the Caribbean Sea (BMT, 1986)*[3]

5.3.3 Extreme weather phenomena and natural disaster risks

During the hurricane season between June and November, various types of cyclone wind phenomena may occur, classified and characterized as follows:

- Tropical depression – sustained wind speed $\leq 10 - 17$m/s ($\leq 20 - 34$ knots)
- Tropical storm – sustained wind speed $\leq 18 - 33$m/s ($\leq 35 - 64$ knots)
- Hurricane – sustained wind speed > 33 m/s (> 64 knots)

Tropical storms and hurricanes are relatively rare and the figure below indicates that 6 tropical storms (blue) and 1 severe hurricane (red) occurred within 60 nautical miles from Trinidad (StormCarib, 2011) during the period from 1944–2010.

[3] Area 47, BMT Global wave statistics.

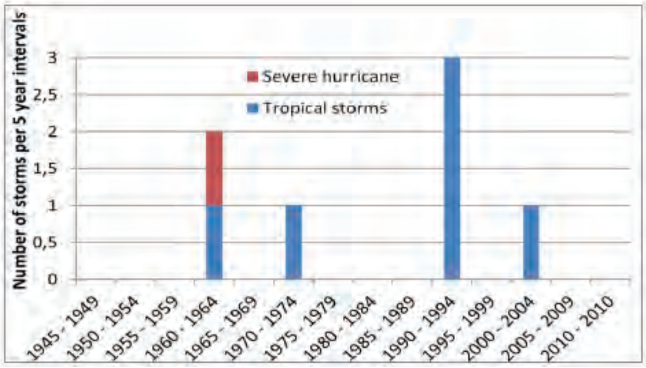

Figure 39: *Statistics on tropical storms and hurricanes in Trinidad from 1944–2010*

5.3.4 Other extreme conditions and phenomena

Heavy rainfall occasionally causes flooding of the streets in Port of Spain, which may affect land based traffic and transports to the terminal area.

5.4 Identified hazards associated with the proposed activities and facilities

General safety issues and potential hazards associated with the presented LNG supply chain options and bunkering activities and facilities were discussed at a meeting at the Port Authority of Trinidad and Tobago in Port of Spain on September 18. Representatives from PATT, TTIT, competent authorities, operators, gas companies and other stakeholders involved in planning and regulating issues regarding the ferry services participated in the meeting. Based on hazard identification experience from other LNG establishment projects and with input from the discussions in Port of Spain, a number of hazards and potential accident scenarios have been identified for the presented LNG supply chains and bunkering arrangements, respectively.

Each of the hazards and accident scenarios are briefly described below and denoted with an identification number, where the first digit refers to the supply chain option number and the second digit is a serial number.

The identified hazards described below primarily represent events with leakage of LNG or gas release occurring during transfer of LNG from one storage vessel to another. It is well verified that hazards and potential leakage or release situations occasionally occur under such circumstances but practically never occur when the LNG is stored in a closed tank.

The indicative maximum spill quantities estimated for the various events are rough estimations representing worst case scenarios and should be refined when a detailed design is outlined. For the risk assessment phase, credible spills scenarios based on small leakages rather than complete tank ruptures should be analysed, and the resulting LNG releases may be in the order of one tenth compared with the indicated worst cases.

5.4.1 Supply chain 1 – Truck delivery

The first case is based on truck delivery of LNG bunker at the quayside of the ferry berth in the Port of Spain ferry terminal. One tank truck may supply a maximum of approximately 20 to 22 tonnes, and hence two trucks are needed for a supply of 30 tonnes in one hour. Experience from LNG bunkering of the **VIKING GRACE** and the Fjordline ferries demonstrates that two trucks may conduct bunkering simultaneously at a high rate by using a common T-connection manifold. For the bunkering scenario outlined in chapter 3, it is, however, assumed that the trucks will bunker the ferry one by one, as the available time slot for bunkering is not critically short.

Hazard No. 1.1 – Traffic accidents with LNG truck with leakage/fire

The two LNG trucks will conduct two return trips each from Point Fortin or La Brea to the Port of Spain ferry terminal. The four movements with loaded LNG trucks per day to Port of Spain represent an increment of the number of hazardous cargo transports in Trinidad. According to the suggested transport schedule for the LNG trucks, morning as well as afternoon rush hours are avoided but the transport may still be associated with risks for traffic accidents resulting in leakage and fire in the LNG truck. High speed ditching or collisions may damage tank vents or valves resulting in limited LNG releases and fire. Large scale tank rupture is not considered a credible result of a traffic accident.

It is presupposed that the Port of Spain ferry terminal is accessible for transport of dangerous cargo such as LNG by roads and streets, without restrictions or requirements for using specific dedicated hazmat roads.

Hazard No. 1.2 – Leakage of LNG and ESD activation during bunkering

Bunkering from the LNG truck to the ferry is conducted via a flexible hose. The truck is parked on the quayside close to the ferry's bunker station. The hose dimension used for LNG trucks typically has a diameter of 2½ inch (DN65)[4] and a maximum bunkering flow rate is assumed to be 40 m^3/h (flow speed in hose about 3.5 m/s). A leakage from a flange, valve or from a crack in the hose will immediately be detected by the bunkering supervisor or by gas detectors at the ferry's bunker station. The Emergency Shutdown System (ESD) in the tank truck will be activated automatically or manually.

Assuming that the ESD will be activated with pump shutdown and valves closed in 4 seconds, a maximum leakage from a 10 m long hose is estimated to be 76 litres of LNG corresponding to 46 m^3 of natural gas when evaporated. This maximum outflow can only be manifest with a most unlikely guillotine type of hose break where the flow rate continues during the ESD time and the entire content in the hose is released. The outflow from a flange or valve failure would be significantly lower, and a credible hose damage scenario with a crack or hole in the hose (crack length 1/3 of the hose diameter) would also result in a significantly smaller outflow.

5.4.2 Supply chain 2a – Local production close to ferry terminal

A local liquefaction plant and storage tank with a capacity 180 m^3 will be located in the vicinity of the ferry terminal and connected via a vacuum insulated cryogenic pipeline to a fixed LNG bunkering manifold at the ferry berth. Due to the limited space in the present ferry terminal, it is not anticipated that it would be possible to locate the liquefaction plant and storage tank in the ferry terminal area, but possible feasible areas may be found at the South quay, within the Sea Lots area or possibly north west of the terminal area if the present shipyard activities are relocated in the future. The pipeline length from the South quay would be approximately 500 m, and from the present ship repair yard about 250 m while the distance from Sea Lots would be closer to 1 000 m.

The bunkering pipeline is assumed to be designed with double walled vacuum insulated tubes and with a system for recirculation of LNG in order to keep the pipes continuously cold. The intermediate storage tank design is assumed to be one horizontal or vertical semi-pressurized vacuum insulated tank with a total capacity of 180 m^3. Connections for filling, ship bunkering and vapour return will be arranged as well as equipment for pressure build up for regulation of tank pressure. Transfer of LNG during bunkering may be achieved by pressure differences or by an LNG pump. The bunkering line may be arranged by a fixed pipe system from the tank in combination with a short flexible hose connection to the ship or by fixed pipes combined with a small-scale loading arm on the quayside at the ferry berth.

Hazard No. 2a.1 – Leakage from the local small-scale liquefaction plant or tank

The LNG production capacity and flow from the plant to the tank is small compared with the flow rates present during the bunkering phase. The plant and intermediate storage tank will require a construction permit from local authorities, and associated risk assessment procedures may stipulate a minimum distance to other building and areas of 50 to 100 m, containment bunds and continuous manning, etc.

Hazard No. 2a.2 – Leakage from bunkering pipeline due to heating and pressurization

Even if the pipe is well insulated, a continuously circulating partial flow is needed to compensate for heat exchange and prevent increasing pressure of the LNG in the pipe. Unintentional closing of valves in the circulation flow may generate heating and pressurization of the LNG contained in the pipeline. Arrangements with pressure monitoring, safety valves, vent masts and redundant circulation systems will be required.

Hazard No. 2a.3 – Leakage from bunkering pipeline due to lack of monitoring or sabotage

If the pipelines are long and cannot be continuously monitored by security guards, intentional damage or sabotage actions may lead to release of LNG. Automatic pressure monitoring and leakage detection will close the flow and isolate the leakage.

[4] Equivalent European designation DN (diamètre nominal) in which sizes are measured in millimetres.

Hazard No. 2a.4 – Leakage from bunkering pipeline, manifold or hose connection during bunkering and ESD activation

When bunkering from the intermediary storage tank via the pipeline, leakage may occur in valves, fixed pipeline sections, manifold or loading arms at the ferry berth or in flexible hose connections utilized for the last section to the flange in the ferry's bunker station. The pipe/hose dimension used for this bunkering arrangement typically has a diameter of 4 inches (DN100) and a maximum bunkering flow rate, which is assumed to be 60 m^3/h (flow speed in pipe/hose about 2.1 m/s). A leakage from a flange, valve or from a hole in the pipe or crack in the hose will immediately be detected by the bunkering supervisor or by gas detectors at the ferry's bunker station and the Emergency Shutdown System (ESD) will be activated automatically or manually.

If the bunkering arrangements also include utilization of the LNG circulation pipeline for return flow of Boil Off Gas (BOG) from the receiving LNG fuelled ferry, leakage scenarios may also involve release of BOG. The flow of the BOG is, however, significantly smaller than the bunkering rate.

Assuming that the ESD will be activated with pump shutdown and valves closed in 4 seconds, a maximum leakage from a 10 m long hose is estimated to 148 litres of LNG corresponding to 89 m^3 of natural gas when evaporated. This maximum outflow can only be manifest with a most unlikely guillotine type hose break where the flow rate continues during the ESD time and the entire content in the hose is released. The outflow from a flange or valve failure or pipe would be significantly lower.

5.4.3 Supply chain 2b – Small-scale local production and trucking to PoS

If the small-scale local production facility is located more than 500 to 1000 m from the Port of Spain ferry terminal, it is likely that truck delivery and TTS bunkering is becoming more attractive and efficient than supply chain 2a. The investment and operational costs for such an LNG pipeline exclusively used for fuelling the ferries will be high compared with the cost of an LNG truck.

Identified hazards and accident scenarios for this LNG supply include the following hazards – the scenarios may occur both in Port of Spain or in Scarborough:

Hazard No. 2b.1 – Leakage from the local small-scale production plant

This hazard is similar to Hazard No. 2a.1

Hazard No. 2b.2 – Traffic accident with LNG truck with leakage/fire

This hazard is similar to Hazard No. 1.1

Hazard No. 2b.3 – Leakage from bunkering hoses/pipes during TTS bunkering

This hazard is similar to Hazard No. 1.2

5.4.4 Supply chain 3 – Bunker barge

With a bunker barge capacity of 1 500 m^3 of LNG in two horizontal semi-pressurized vacuum insulated tanks the barge may need to return to its loading terminal every tenth day in order to be able to supply 60 tonnes per day to the ferry terminal. The bunker vessel will moor alongside at the outside of the receiving ferry. Any potential interference with activities and handling of cargo or passengers on the quayside is thereby prevented.

Hazard No. 3.1 – Navigational/maritime accident with bunker vessel or barge

The bunker barge is supposed to regularly do sea voyages to an LNG export facility (in Point Fortin) and it will also conduct daily movements from its own dedicated berth in the Port of Spain to the ferry terminal for bunkering the ferries. The manoeuvring and mooring of the bunker barge alongside the high speed ferries involves turning manoeuvres close to other vessels and possibly also by use of more than one tug vessel. These manoeuvres may involve collision risks that may cause damage to the bunker barge, ferry or tug. It is considered very unlikely that any credible collision scenario may involve energy levels high enough to cause damages jeopardizing the integrity of the LNG containment on the bunker barge or on the ferry.

Hazard No. 3.2 – Drift off or breakaway scenario with activation of the ESD2

Ship to ship (STS) bunkering requires that the relative motions between the ships are controlled and kept within the operational envelope specified for the bunkering arrangement. Excessive relative motions may be induced by large wave action, mooring failure or by collision/contact from third party vessels. If such an event occurs, the STS bunkering arrangement includes an ESD2 device with a dry breakaway coupling disconnecting the bunker line between the ships. The free ends of the breakaway couplings are automatically closed and the released amount of LNG is very small.

Hazard No. 3.3 – Leakage from bunkering line during ship bunkering and activation of the ESD1

Bunkering from the LNG bunker barge to the ferry is conducted via a flexible hose. The bunker vessel is moored alongside the ferry close to the ferry's bunker station. The hose dimension used for LNG hose is assumed to have a diameter of 2½ inch (DN65) and a maximum bunkering flow rate is assumed to be 40 m^3/h (flow speed in hose about 3.5 m/s). A leakage from a flange, valve or from a crack in the hose will immediately be detected by the bunkering supervisor or by gas detectors at the ferry's bunker station and the Emergency Shutdown System (ESD) in the LNG bunker barge will be activated automatically or manually.

Assuming that the ESD will be activated with a pump shutdown and valves closing in 4 seconds, a maximum leakage from a 10 m long hose is estimated to be 76 litres of LNG corresponding to 46 m^3 of natural gas when evaporated. This maximum outflow can only be manifest with a most unlikely guillotine type hose break where the flow rate continues during the ESD time, and the entire content in the hose is released. The outflow from a flange or valve failure would be significantly lower and a credible hose damage scenario with a crack or hole in the hose (crack length 1/3 of the hose diameter) would also result in a significantly smaller outflow.

5.4.5 Maximum spill in case of guillotine hose rupture

The probability of a guillotine hose rupture is extremely low, and credible accidental events with LNG releases are more likely to start with a small leakage from cracks or holes in the hose or from leaking flange gaskets. Normally such leakages are easily detected visually by formation of frost, snow and white vapour.

Table 14 – *Summary for comparative calculation of maximum LNG release in the ship bunkering phase*

Supply chain option and ship bunkering	LNG bunker hose inner diameter	LNG bunker hose length between ESDVs	LNG bunkering flow rate	ESD shutdown time	Max release if guillotine rupture
1 Truck (two trucks shuttling)	2½ inch DN65	10 m	40 m^3/h	4 seconds	76 litres
2a Local production. Pipeline bunkering	4 inch DN100	10 m	60 m^3/h	4 seconds	148 litres
2b Local production. Truck bunkering	2½ inch DN65	10 m	40 m^3/h	4 seconds	214 litres
3 LNG bunker barge. Ship to ship	4 inch DN100	10 m	120 m^3/h	4 seconds	76 litres

Comparative calculations for credible design LNG releases can be derived on the basis of the above figures assuming a leakage from a hose crack with a length corresponding to 1/3 of the hose diameter. Further an LNG temperature of −150°C and a pressure of 4 bars may be assumed. These assumptions regarding leakage size, temperature and pressure are considered to be conservative as figures tend to overestimate release quantities and flashing behaviour.

5.4.6 Ranking of identified hazard

The LNG transfer interfaces taking place in the ferry terminal are considered more important from a safety point of view because of the number of simultaneous activities going on in the area and the number of passengers and vehicles that are present.

The LNG tank truck accident was considered high ranking during the workshop in Port of Spain and is, therefore, ranked high in the list below. The other hazards are indicatively ranked with regard to the associated maximum LNG releases in case of a guillotine hose break.

Table 15 – *Summary and indicative ranking of identified hazards*

Hazard Id Number	Description
Hazard No. 1.1	Traffic accident with LNG truck with leakage/fire
Hazard No. 1.2	Leakage of LNG during bunkering and ESD activation
Hazard No. 2a.1	Leakage from the local small-scale liquefaction plant or tank
Hazard No. 2a.2	Leakage from bunkering pipeline due to heating and pressurization
Hazard No. 2a.3	Leakage from bunkering pipeline due to lack of monitoring or sabotage
Hazard No. 2a.4	Leakage from bunkering pipeline, manifold or hose connection during bunkering and ESD activation
Hazard No. 2b.1	Leakage from the local small-scale production plant
Hazard No. 2b.2	Traffic accident with LNG truck with leakage/fire
Hazard No. 2b.3	Leakage from bunkering hoses/pipes during TTS bunkering
Hazard No. 3.1	Navigational/maritime accident with bunker vessel or barge
Hazard No. 3.2	Drift off or breakaway scenario with activation of the ESD2
Hazard No. 3.3	Leakage from bunkering line during ship bunkering and activation of ESD1

5.5 Risk assessment

The basic risk assessment and management approach is based on objectives to prevent LNG release and to control the ignition sources in case LNG is released. If situations regarding release of LNG are defined as top events, fault tree structures and preventive safety barriers to the left and event tree structures with mitigating safety measures on the right, can be illustrated and modelled according to the bowtie approach shown in the figure below.

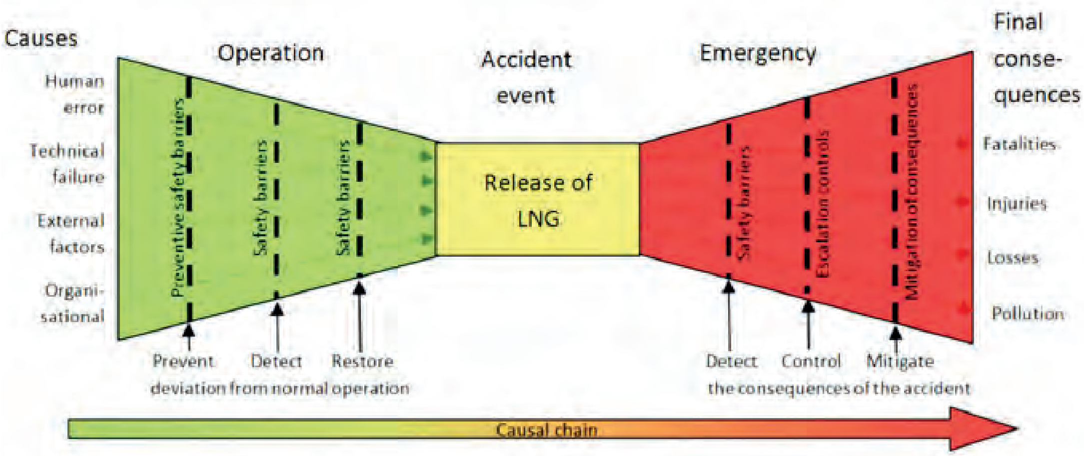

Figure 40: *The bowtie approach with safety barriers*

For each of the prioritized accident scenarios a quantitative risk assessment may be conducted as soon as more detailed information on the technical layout and capacities have been outlined in the design phase. Probabilities and consequences for the identified scenarios will be estimated and described but at the present preliminary design stage, only some general figures and qualitative considerations are presented.

Consequences of LNG leakage scenarios are primarily analysed in view of potential fire scenarios where heat radiation may lead to injuries or fatalities of port personnel, ship crew, passengers or other third party persons. Environmental or economic consequences may also occur, but these are usually less critical than human life and health safety aspects.

5.5.1 Hazards associated with road accidents with LNG truck

Collisions or ditching accidents may occur but, based on experience and by safe design, leakage and fire scenarios are considered unlikely.

Probability

A large number of LNG tank trucks are operating in the world today and show excellent safety records. A few tank truck accidents with liquefied gas have been reported and have gained a lot of media interest. Most of these accidents, however, were not LNG but other flammable gases like LPG. One of the most well-investigated accidents involved a Spanish LNG tank truck exploding on 22 June 2002 near Tivissa in Catalonia. The accident involved a tank design that was not specifically intended for transportation of LNG and is not in use today for road transportation of LNG. In the double walled vacuum insulated tank, the distance between the inner and outer tanks was filled with polyurethane foam that melted when heated and the liquid thereby formed a heat bridge from the outer to the inner tank shell.

Consequences

If leakages occur, it is important to secure the surroundings, evacuate people in the vicinity and prevent the introduction of ignition sources. Even if there is no damage to the LNG tank, fire may occur involving the truck fuel. The tank design has a high level of passive fire protection, but cooling may be important to prevent heating of the tank contents.

5.5.2 Hazards associated with leakage from LNG hoses or loading arms

Most of the identified accident scenarios are associated with leakages from hoses or loading arm connections or valves. These hazards are, therefore, discussed together below, presenting examples of general failure probabilities and consequences.

Probability

The following figures for failure probabilities have been presented and used for safety assessment of LNG terminals.

Rupture of flexible LNG hose	Probability $5.4 \cdot 10^{-7}$ per hours of use
Leakage from flexible LNG hose	Probability $5.4 \cdot 10^{-6}$ per hours of use
Rupture of fixed loading arm	Probability $3 \cdot 10^{-8}$ per hours of use
Leakage from fixed loading arm	Probability $3 \cdot 10^{-7}$ per hours of use

The above figures (Fluxys, 2012) indicate that rupture failures are about 10 times less probable than hose/pipe crack/hole leakage failures. Leakage scenarios are, therefore, usually considered important design cases in safety assessment of LNG transfer installations and operations.

The listed probability figures also indicate that the failure frequency of fixed arms should be about 10 lower than for flexible hoses. The figures are, however, based on a limited amount of historically registered failure statistics, and operators using flexible hoses for LNG handling today apply stringent quality control and claim that flexible hoses also show excellent performance and low failure frequencies. Fixed arm solutions for LNG bunkering purposes may require a large number of rotatable swivels with ceilings that also require regular checks for wear and tightness.

Consequences

The outflow quantity from hose or pipe leakages is, of course, dependent on the size of the leakage. For hose and pipe leakages, a crack length of 1/3 of the hose/pipe diameter or a leakage hole diameter of 1/10 of the hose/pipe diameter is often used as a credible reference damage for outflow calculations. In addition to the size of the leakage, the following parameters are also important for estimation of the total outflow from the leak and the leakage rate:

- ESD activation time
- ESD shutdown time
- Hose/pipe dimensions, diameter and length from ESD valves
- Flow rate of LNG in transfer line
- Pressure and temperature of LNG in transfer line

The time for detection of leakage and activation of the ESD may vary greatly depending on the type of detection devices and function of the ESD, which may include manual or automatic systems. In small-scale systems, the design may allow immediate closure of the ESD valves, but in large-scale systems pumps and valves must be ramped down successively over a period of time in order to avoid excessive surge pressure. Large-scale systems typically have a 28 second shutdown time, whilst small-scale systems may be closed off in a few seconds.

For small-scale bunkering activities like the described LNG truck or LNG barge bunkering with flow rates ranging from 40 to 120 m^3/h and typical hose dimensions of 4 to 6 inches, the ESD time is often dominated by the component related to detection or reaction of the leakage, which may be up to 10 seconds. The component related to valve closing can be estimated to 2 s for DN25, 5.2 s for 2½ inch (DN65) and 8 s for a 4 inch (DN100) valve (LNGA, 2010).

In case of a hose/pipe rupture it is obvious that the total outflow volume will be a function of hose diameter, length, flow rate and the shutdown time. For leakage scenarios the pressure will influence the leakage rate significantly and the rate will be a function of the specific hole diameter or crack length. In addition the temperature will affect the character of the outflow so that a "warm" LNG (for example at –140°C) may appear as a two-phase spray where the liquid LNG is immediately evaporated whilst cool LNG (–160°C) may remain liquid with potential pool formation when released. These different characters may also influence the character of the potential fire if the leak is ignited.

In addition to the quantity of released LNG, the potential consequences of fire scenarios in terms of heat radiation will be different if the outflow is ignited immediately or if the ignition is delayed. In detailed risk analyses, various established gas dispersion/fire and heat radiation models are applied to estimate radii for specific critical radiation levels at representative weather/wind conditions.

The figure below is a schematic illustration of calculated heat radiation levels, and it indicates how these are applied in the risk control phase for defining safety zones and risk distances.

The maximum radii of heat flux threshold levels for the various fire scenarios (pool fire, jet flame or flash fire) are often plotted in a map as isoline contours for 5, 12 or 15 kW/m^2. Predominant wind conditions are taken into account and potential heat shielding or barrier effects from building, ship freeboard side, may also be considered in the model calculations, as illustrated above.

A level of 5 kW/m^2 is often used, e.g. in NFPA 59A, as the criterion for determining the hazard distance to people exposure from an LNG fire.

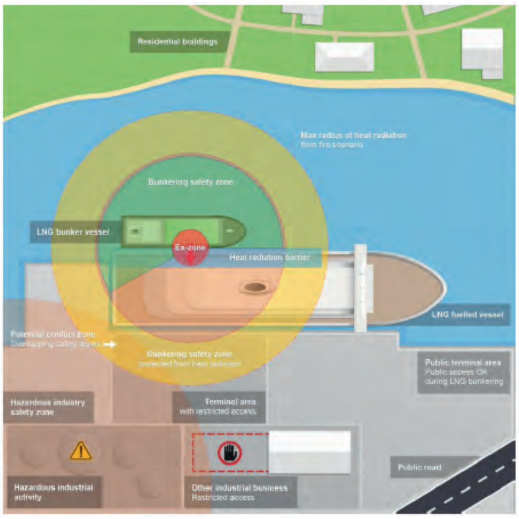

Figure 41: *Schematic illustration of how a credible design LNG leakage scenario is used for input to model calculations of gas dispersion and heat radiation from associated fire scenarios*

5.6 Risk control

The four cases outlined for optional and stepwise expansion of development of LNG bunkering arrangements in the Port of Spain ferry terminal generate different requirements for safety zones and risk distances primarily in relation to the quantities of LNG handled. When the risk levels are estimated for the respective cases, it is presupposed that a number of important risk control options are in place and have been adapted to the specific bunkering arrangement and risk profile. The detailed layout and design may be different for the different cases, but a number of common risk control options can be identified for small-scale bunkering arrangements as well as for large-scale bunkering terminals. The examples listed below are not intended to show a complete list but provide an overview of examples of important risk control options to be elaborated on and implemented for LNG bunkering facilities in the Port of Spain. The checklist of 24 essential safety functions given in ISO, 2013 provides additional information.

5.6.1 Operational procedures

Safety procedures including checklists and detailed sequential descriptions of all phases of the bunkering operation from mooring to departure of the receiving vessel will be established. Roles and responsibilities for all involved staff ashore on the quayside, the crew on the receiving vessel, bunker vessel and tank truck driver should be clearly defined and well known. The entire bunkering operation must be surveyed by a dedicated watch.

Established routines are necessary for ship specific safety assessment and permit procedures when new LNG receiving vessels are to be bunkered. Routines for safety assessment are also required if LNG bunkering are to be introduced and conducted at new sites or berths in the Port of Spain.

5.6.2 Technical measures and devices

All LNG bunkering equipment and procedures will be designed so as not to allow any emission of methane during normal bunkering operations. This implies, for example, that the following measures and devices will be used:

- Use dry disconnect couplings to prevent any spill when decoupling
- BOG return or pressure control system for receiving ships and for filling of land based intermediate storage tanks. No planned venting of BOG from tank ullage
- Natural gas purging and nitrogen inerting system of LNG hose and piping systems when bunkering is completed

In order to prevent accidental spills due to human handling failure or mistake, the ships' LNG bunkering station as well as the supply services or bunker terminal in the port must have standardized connections for LNG fuel with a mechanical single action coupler without any need for manual bolting. To the extent possible, failsafe system design should be applied to minimize influence of mistakes by operators.

The bunkering system shall be designed with double safety barriers in order to prevent any spill due to a single failure.

In case of excessive relative motion of the LNG receiving vessel, or if a leakage is detected in the LNG transfer or BOG return line, an emergency shutdown, the ESD system must be in place. The ESD control system between shore and ship systems shall be linked and bunkering shutdown can be initiated either from the LNG supplier side or from the LNG receiving vessel by automatic failure detection system or by manual control. The ESD link and routines shall include possibilities for direct communication.

The ESD, pump, valve and piping design will allow for immediate shutdown during bunkering operations without risk for excessive surge pressure. For small-scale bunkering systems 0 to 5 seconds, and for large system 10 seconds, may be considered as target values.

The ESD system will include a dry breakaway coupling (ESD2) to prevent spillage or damage to other equipment in case of dislocation or drift off of the receiving vessel or relative motions exceeding the operational envelope of the bunker connection.

All LNG fuelled vessels to be bunkered, the bunker vessel and land based facilities for supply of LNG bunker shall be designed to withstand any cryogenic damage in case of exposure of LNG spills. These design requirements include the use of cryogenic safe construction materials (for first and second barriers), drip trays to be fitted and water curtains to be used along the hull side.

5.6.3 Training and education

For officers and crew certificated according to the IGC code on LNG bunker vessels there are stringent and well-defined requirements for training, competence and operational experience at sea. For non-self-propelled LNG bunker barges, the IGC code does not apply, and the manning and qualification requirements are less stringent. Qualification requirements for chief officers in LNG fuelled ships are under development.

LNG tank truck drivers also have specific training on LNG transfer and bunkering operations and emergency procedures in case of spills or accidents. For operational staff of the LNG bunkering facilities in the port there are no detailed prescribed regulations for training or education. For safe operation of LNG bunkering in the Port of Spain, it is, however, of utmost importance that the land based staff involved in LNG bunkering operations is well trained and qualified to handle all normal procedures and take action in case of emergencies.

For each vessel to be bunkered and for each site or berth where bunkering operations are going to take place, all involved staff and crew must be familiar with checklists, procedures and safety routines. Regular training and drills involving bunkering personnel as well as port safety officers and municipal rescue services are recommended. It is also recommended to elaborate a short LNG bunkering familiarization training/information for other personnel and operational staff in the port.

5.6.4 Emergency preparedness and contingency plans

Emergency preparedness procedures for any type of possible incident and accidental event during bunkering operations should be established in the Port of Spain and coordinated with the municipal rescue services of the city. Corresponding preparedness should, of course, also be arranged in Scarborough if LNG bunkering is to take place there. The preparedness shall include a plan for change in safety alert levels and a plan for safe evacuation of the bunkering site/terminal and adjacent areas at risk.

5.6.5 Public participation and hearing

Handling of LNG as fuel is a new activity in most ports, and the public sometimes react with uneasiness due to a lack of knowledge and unrealistic perception of the risks associated with LNG. Public consultation is an important part of the permit procedure and EIA process in most countries, and normally the public will be informed early in the decision-making process. Adequate information on the risks as well as on the environmental benefits to the public by consultation and hearings may be important in order to prevent delayed processing and to sustain focus on relevant safety issues.

5.7 Risk evaluation

In the risk evaluation phase the identified and quantified output from the risk assessment phase is evaluated and compared with established risk acceptance criteria or target levels of tolerable risks. Some countries have established risk acceptance criteria to be applied and validated by quantitative risk assessments for infrastructure and industrial development projects.

Such criteria usually specify both societal and individual risk levels and define ranges where safety measures should be taken to reduce risk levels to "as low as reasonably practicable" (ALARP). The numerical figures of the limiting levels vary slightly from different countries and industrial organizations but may serve as a basis for risk evaluation and identification of hazardous activities and operations.

It is also important to note in this context that quantitative risk assessments (QRAs) are always associated with assumptions and numerical inaccuracies.

5.8 Comparison of the LNG supply chains from a safety perspective

This risk assessment addresses general safety issues and outlines a basic structure to be applied in the formal permit application process including safety assessment of the first step of the LNG bunkering plans for the Port of Spain.

This study identifies a number of critical interfaces associated with the potential release of LNG and fire hazards and exemplifies how these hazards can be quantified in terms of accident probabilities and consequences. Based on established practices and best available technology considerations, a number of important risk control options are also described and recommended. The importance of standardization of LNG bunkering couplings and safety hardware is stressed as well as training needs and other soft safety aspects.

All the identified and described LNG supply chains and LNG bunkering arrangements are considered feasible from a safety point of view, but additional quantitative studies are recommended to be conducted when the design of LNG supply chain and the ferry concept have been elaborated on in greater detail.

5.8.1 LNG bunkering in Port of Spain ferry terminal

The TTS LNG bunkering concept is considered to be possible to design and arrange in Port of Spain to meet a high level of safety if bunkering is conducted without passengers on board the vessel. With passengers on board or disembarking/embarking, it is not recommended to conduct TTS LNG bunkering with the present terminal layout in Port of Spain. The unprotected passenger gangways and traffic situation close to the present bunkering location may cause hazardous situations, introduction of ignition sources and difficulties with evacuation of passengers in case of incidents or emergencies.

A designated ITPS LNG bunkering concept is not recommended with the present terminal layout in Port of Spain, irrespective if bunkering is to be conducted with or without passengers on board, as there is no obvious site in the terminal area where an intermediate storage tank can be located with safe separation from traffic and passenger flows and adjacent port activities. With a modified terminal layout allowing for more space, in the future possibly also incorporating the neighbouring shipyard area, it may be possible to accommodate an ITPS facility for LNG bunkering of the ferries. If an ITPS LNG bunkering concept is to be designed for parallel bunkering and passenger and cargo handling, a detailed risk assessment will be needed in the design phase to ensure safe pipe design and routing and barriers for protection and separation of cars and unprotected passengers and staff in the port.

An STS LNG bunkering concept is considered less difficult from a safety point of view provided that the bunker station on the ferry can be arranged so that the bunker barge can moor alongside and still remain at a distance from the quay and loading ramps of the ferry. The bunkering area will then not be accessible to passengers, and the bunker barge will be free to depart without any interaction with other port activities. It is possible that safety measures, zoning and barriers may be designed in order to allow LNG bunkering with passengers on board and parallel cargo handling but this will need to be subject to detailed risk assessment studies. Adequate safety zones and risk distances need to be determined from credible design LNG releases and depend on the bunkering flow rate and other bunkering characteristics.

The figure below illustrates the differences between the TTS and STS LNG bunkering in terms of interference with loading ramps and passenger access areas based on a tentative 25 m radius safety zone around the LNG tank truck and the ferry bunker station and a corresponding zone around an STS LNG bunkering amidships of the high speed ferry. The yellow area indicates a radius of approximately 100 m, showing that the terminal building and other buildings in the shipyard area are located within 100 m from the indicated TTS LNG bunkering site.

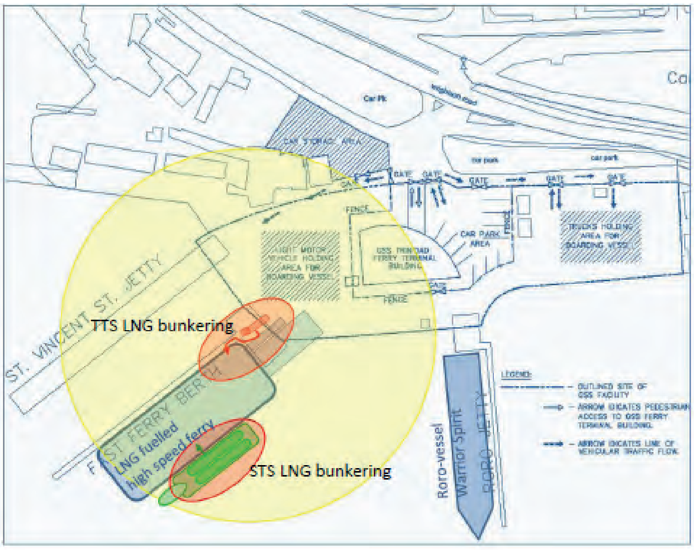

Figure 42: *Comparison of indicative 25 m safety zones in Port of Spain for TTS and STS bunkering*

5.8.2 LNG bunkering in Scarborough ferry terminal in Tobago

The TTS LNG bunkering concept is considered possible to design and arrange in Scarborough to meet a high level of safety. If the bunkering station on the vessel is located as today's fuel oil bunker station near the aft passenger ramp, it would not be possible to bunker LNG with passengers on board or during embarking/disembarking or cargo handling. If the bunker station for LNG fuel is located amidships on port side it may, however, be possible to arrange LNG bunkering in parallel with cargo handling and with passengers on board. The quay areas alongside and in front of the berthed high speed ferry in Scarborough are relatively large, have good access for vehicles and the distances to other buildings and residential areas are approximately 100 m or more. The spacious quay areas may also allow for the design of a designated ITPS LNG bunkering facility in Scarborough. If an ITPS LNG bunkering concept is to be designed for parallel bunkering and passenger and cargo handling, a detailed risk assessment will be needed in the design phase to ensure safe barriers for protection and separation of passengers, staff and other cargo handling activities in the port.

The figure below illustrates how TTS LNG bunkering may be conducted amidships on port side with tentative 25 m radius safety zone around the LNG tank truck and the ferry bunker station that does not interfere with the car ramps and passenger gangways at the aft of the ship. The yellow area indicates a radius of approximately 100 m, showing that there are only a few buildings partly inside this area and most of the areas are open quay areas.

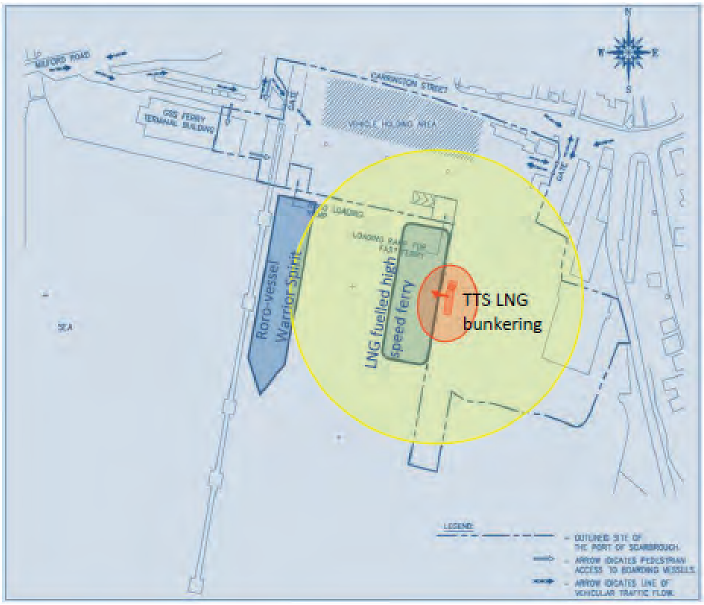

Figure 43: *An indicative 25 m safety zone surrounding a TTS LNG bunkering arrangement in Scarborough ferry terminal*

TRINIDAD AND TOBAGO

TRINIDAD AND TOBAGO

6
Cost estimations for newbuildings, retrofit and LNG infrastructure

6.1 Newbuilding

6.1.1 FRANCISCO

The only LNG fuelled high speed vessel present is the previously mentioned **FRANCISCO**, built by Incat in Australia and operated by Buquebus between Argentina and Uruguay. No official price is available, but according to several informal sources, the indication of the price delivered was around 130 million USD.

This price is estimated to be approximately 30% higher than a diesel fuelled vessel of the same size and capacity which is a somewhat higher ratio than for other ship types that are generally estimated to be 10% to 20% more expensive if LNG fuelled than if equipped with conventional diesel engines.

The relatively high additional cost for the LNG fuelled vessel in this case may be related to the fact that no vessel similar to the LNG fuelled **HSC FRANCISCO** has ever been designed and constructed. Therefore a lot of development work was needed, and the shipyard and other involved stakeholders were more risk exposed than for conventional newbuilding projects.

6.1.2 Replacement vessels

If TTIT decides to invest in one or two LNG fuelled newly built replacement vessels with similar capacity and performance as the present vessel, the newbuilding price is estimated to be approximately 100 million USD each. If compared with the **FRANCISCO**, the speed requirements are lower for the evaluated route, reducing the cost for machinery and fuel storage systems. Another cost reducing benefit is that thanks to the building of the **FRANCISCO**, there is more experience available today for reducing some of the risks related to the design and construction of LNG fuelled HSC.

6.2 Conversion of T&T SPIRIT

It has been deemed possible yet challenging to convert the **T&T SPIRIT** to be able to operate as a dual fuel vessel. The main consequence would be that she would lose a significant part of her high vehicle capacity (>1.8m) due to the installation of the LNG tanks and vaporizers on the main car deck.

6.2.1 Main engines

Due to the limited availability of light and high performance dual fuel piston engines, it would be necessary to use gas turbines as the main propulsion power if converting the **T&T SPIRIT**. The main benefit of gas turbines is a significantly higher power to weight and size ratio as well as low maintenance and lube oil costs. They are well proven in maritime installations, and in general have a higher reliability than normal piston engines. The main drawbacks are high procurements costs and low fuel efficiency.

Since gas turbines are operated in a completely different rpm range the gear boxes also have to be replaced. Today the **T&T SPIRIT** has two diesel engines in each hull with a MCR of approximately 7 000 kW. For efficiency and cost, it has been decided to replace the two present diesel engines in each hull with one large gas turbine of approximately 14 000kW. A new gearbox with one input shaft and two output shafts connected to the present water jets is also a necessary investment.

Air inlets, exhaust outlets as well as engine room ventilations will also require updates due to the installation of gas turbines.

6.2.2 Fuel system

To be able to do one round trip fuelled with LNG the **T&T SPIRIT** requires an LNG capacity of approximately 75 m^3 corresponding to the demand of 30 tonnes of LNG per round trip. To fit the fuel tanks in the ceiling of the main car deck the volume will be divided into three tanks of approximately 25 m^3 capacity each.

6.2.3 Total cost

The following table indicates the main cost components of a conversion of **T&T SPIRIT**.

Component	Estimated cost	Source of information
Fuel system	2 500 000 USD	(Patel, 2013)
Gas turbines	24 700 000 USD	(Lundgren, 2013)
Gear box	1 800 000 USD	(Lundgren, 2013)
Ventilation and exhaust	500 000 USD	
Design and classification	600 000 USD	
Miscellaneous	1 900 000 USD	
Total	**32 000 000 USD**	

Figure 44: ***T&T SPIRIT*** *approaching Port of Spain*

6.3 Operational costs for LNG fuelled high speed vessels

6.3.1 Crew and education

As described in section 4.2.5, there is no international regulation in force concerning the crew on gas fuelled vessels. It is up to the flag State to approve an adequate scope of education and training for all crew on board an LNG fuelled vessel. If the recommendation in section 4.2.5 is followed it is estimated that the educational cost related to the usage of LNG as fuel would be approximately 6 000 USD per deck and machinery related crew members and about 2 500 USD for all other crew members (Nylund, 2013).

6.3.2 Maintenance

Due to the limited number of comparative types of vessel in operation it is difficult to establish a clear picture of the maintenance costs of LNG fuelled high speed vessel in relation to diesel fuelled, especially as a change from piston engines to gas turbines is also considered.

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A general conclusion based on vessels used in Scandinavia is that even if the number of necessary measures in relation to maintenance and repairs are usually less, each measure is usually more expensive due to more specialized service staff and more expensive spare parts. It is, therefore, generally assumed that the overall cost for maintenance and repairs is similar to conventional vessels.

Maintenance of gas turbine machinery is performed strictly according to a schedule of preventive maintenance actions, based on equivalent operating hours accumulated on the particular gas turbine unit (Sörensson, 2013).

The lowest level of such a maintenance programme is performed by the crew on a daily or weekly basis, and include activities such as:

- Check for leaks
- Check for proper operation and instrument readings
- Log and verify important readings
- Check for filter differential pressure
- Inspection of air intake filter condition
- Lubrication oil tank level

When the preventive maintenance programme is observed, experience from similar operations has proven that breakdowns or unscheduled disturbances are extremely rare, resulting in very high reliability and availability of gas turbines.

In order to simplify and make the cost for maintenance fully predictable for the shipowner, it is recommended to enter into a service agreement with the gas turbine supplier. The annual cost for such an agreement shall cover full maintenance schedule including all necessary labour and materials.

6.4 LNG bunkering infrastructure

Each of the supply chains described in sections 3.5 to 3.7 is designed to deliver 30 tonnes of LNG two times per day to the two high speed vessels in operation between Trinidad and Tobago. For each supply chain an estimated supply cost per tonne is presented below. When comparing the figures it is important to note that the actual price of LNG or natural gas is not included in any of the price calculations since that is highly unpredictable, dependent on political decisions and therefore not included in the scope of this study. To create true comparative figures, such prices have to be established and added.

It is also important to understand that the utilization rate of some of the equipage in the supply chains is low, indicating that there are possibilities for significant expansion in capacity if other LNG users and customers contribute to an increasing demand.

6.4.1 Supply chain 1; Direct truck supply

As described in section 3.5, the supply chain requires investments in a truck loading facility as well as in two LNG semi-trailers. In addition to the investments in the supply chain, two towing trucks are required to be chartered when needed. The bunkering will be performed by the truck driver with assistance from the ship crew.

Table 17 – *Estimated daily cost for a truck loading facility*

Component	Cost	Comments/Reference
Price Truck loading facility	650 000 USD	Price from ref (DMA, 2011)
Estimated CAPEX	260 USD/Day	8% interest rate. 10 years depreciation time.
Estimated OPEX	180 USD/day	3 USD/ tonnes LNG
Total cost	**440 USD/day**	

In relation to supply chain 1, the truck loading facility will be used only 2 hours per day.

Table 18 – *Estimated daily cost for LNG trucking in supply chain 1*

Component	Cost	Comments/Reference
Price 2 pc of LNG semi-trailers	720 000 USD	Price from Cryo AB (Hörndahl, 2013)
Estimated CAPEX	480 USD/day	8% interest rate 5 years depreciation time
Estimated OPEX	50 USD/day	Maintenance + misc.
Estimated rental cost 2 towing trucks	1 980 USD/day	55 USD/h and truck 18 hours per day
Estimated fuel cost	136 USD/day	0,2 USD/km, 85 km from POS to Atlantic, 2 trucks, 2 return trips/day
Total cost	**2 650 USD/day**	

In relation to supply chain 1 the semi-trailers will be used approximately 18 hours per day implying a high utilization rate.

Table 19 – *Estimated costs related to supply chain 1*

	Per day	Per year	Per tonnes LNG delivered
Total cost	**3 090 USD**	**1 130 000 USD**	**51 USD**

In the table above the total cost is summarized indicating a supply and bunkering cost of 51 USD per tonne delivered to the vessel by supply chain 1. To get a real LNG fuel price, the cost of LNG/tonne at the source has to be added to the 51 USD/tonne.

6.4.2 Supply chain 2; Local production

As described in section 3.6 there are two versions 2a and 2b of supply chain 2. Both are based on local production of LNG but the difference between the two is the location of the production plant. For version "a" the production plant is located in direct proximity of the ferry terminal, and bunkering is conducted by ITPS. For version "b" the local production and storage facility is located close to an already existing pipeline, and the LNG is transported by truck from the production plant to the ferry terminal. The bunkering is done by TTS.

The cost of the local production is deemed similar for both versions of the supply chain.

Table 20 – *Estimated cost of a local storage and production facility for supply chain 2*

Component	Cost	Comments/Reference
Price 1pc Local production and storage facility	26 500 000 USD	Price based on information from Galileo (Gandulfo, 2013) and Cryostar (Bertrand, 2013)
Estimated CAPEX	7 300 USD/day	8% interest rate 20 years depreciation time
Estimated OPEX	4 000 USD/Day	Maintenance + electricity + staff + miscellaneous
Total cost	**11 200 USD/day**	

Additional cost supply chain 2a

Supply chain 2a also requires a bunkering station at the ferry terminal. The cost of such facility is described in in the table below.

Table 21 – *Estimated cost of the bunkering station used in supply chain 2a*

Component	Cost	Comments/Reference
Price Bunkering station	650 000 USD	Price from DMA (DMA, 2011).
Estimated CAPEX	260 USD/day	8% interest rate 10 years depreciation time
Estimated OPEX	180 USD/day	3 USD/ tonnes LNG
Total cost	**440 USD/day**	

Since the local production and storage facility is not located directly at a natural gas pipeline an additional small feeder pipeline is necessary.

The cost of such pipeline is estimated according to the following formula:

price USD = (length i m) * 800 USD + 500 000 USD

The formula is based on information from Skangass (Bjørndal, 2013), Swedgas (Engstrand, 2013) and NGC (Hosein, 2013).

As described in section 3.6, the distance in Tobago is estimated at 7 500 m.

Table 22 – *Estimated cost of the required pipeline for supply chain 2a in Tobago*

Component	Cost	Comments/Reference
Price Pipeline in Tobago	6 500 000 USD	See formula above
Estimated CAPEX	1 790 USD/day	8% interest rate 20 years depreciation time
Estimated OPEX	30 USD/day	
Total cost	**1 820 USD/day**	

In section 3.6 the distance in Port of Spain is estimated at 1 200 m.

Table 23 – *Estimated cost of the required pipeline for supply chain 2a in Port of Spain*

Component	Cost	Comments/Reference
Price Pipeline in Port of Spain	1 460 000 USD	See above
Estimated CAPEX	400 USD/day	8% interest rate 10 years depreciation time
Estimated OPEX	25 USD/day	3 USD/ tonnes LNG
Total cost	**425 USD/day**	

Additional costs 2b

The cost of the truck loading facility is expected to be similar to supply chain 1 with a daily cost of 440 USD.

The cost for the trucking part is estimated according to the table below.

Table 24 – *Estimated daily cost for LNG trucking in supply chain 2b*

Component	Cost	Comments/Reference
Price 1 pc of LNG Semi-trailer	360 000 USD	Price from Cryo AB (Hörndahl., 2013)
Estimated CAPEX	240 USD/day	8% interest rate 5 years depreciation time
Estimated OPEX trailers	25 USD/day	Maintenance + misc.
Estimated rental cost towing trucks	550 USD/day	55 USD/h and truck 10 hours per day
Estimated fuel cost	50 USD/day	
Total cost	**865 USD/day**	

Total cost supply chain 2

The following table summarizes all costs for the different versions of supply chain 2.

Table 25 – *Estimated costs related to supply chain 2*

Total cost	Per day	Per year	Per tonne LNG delivered
2a Tobago	13 430 USD	4 900 000 USD	224 USD
2a Port of Spain	12 000 USD	4 400 000 USD	201 USD
2b	12 500 USD	4 540 000 USD	207 USD

The total production and delivery cost is described in table 25 and indicates a supply and bunkering cost between 201 to 224 USD per tonne delivered to the vessel through supply chain 2. To get a real LNG fuel price/tonne the cost of approximately 1 400 m^3 or 49 500 cft of natural gas delivered to the local production facility has to be added to the above estimated production and supply cost.

6.4.3 Supply chain 3; Bunker barge

As described in section 3.7 the supply chain requires investments in a small-scale jetty and an un-propelled LNG bunker barge. In addition to the investments, the supply chain also requires a tug boat to be chartered when needed.

Table 26 – *Estimated daily cost for a small-scale jetty at the LNG source*

Component	Cost	Comments/Reference
Price Small-scale jetty	45 000 000 USD	(DMA, 2011)
Estimated CAPEX	10 860 USD/day	8% interest rate 30 years depreciation time
Estimated OPEX	180 USD/day	3 USD/tonnes LNG (DMA, 2011)
Total cost	**11 000 USD/day**	

Based on the outlined needs for supply chain No. 3, the small-scale jetty will only be used for 5 hours every tenth day.

Table 27 – *Estimated daily cost for an un-propelled LNG bunker barge*

Component	Cost	Comments/Reference
Price LNG barge	9 000 000 USD	Price of LNG systems from Inox India (Patel, 2013)
Estimated CAPEX	2 475 USD/day	8% interest rate 20 years depreciation time
OPEX	1 000 USD/day	Cargo master + maintenance + miscellaneous
Total cost	**3 475 USD/day**	

Based on prices given by NEC (Scipio-Hosang, 2013), an estimated price of the required tug hire is 5 500 USD/day including one trip to the source every 10th day. The prices include fuel.

Table 28 – *Estimated costs related to supply chain 3*

	Per day	Per year	Per tonnes LNG delivered
Total cost	**19 975 USD**	**7 290 000 USD**	**333 USD**

In the table above the total cost is concluded indicating a supply and bunkering cost of 333 USD per tonne delivered to the vessel through supply chain 3. To get a real LNG as fuel price the cost of LNG/tonne at the source has to be added to the 333 USD.

6.5 Fuel cost estimations and comparison of identified supply chains

Today TTIT operates on MDO subsidized by the government of Trinidad and Tobago. The price is 1.5 TTD/litre equal to a price of 263 USD/tonne. A typical market price for MDO in the WCR is estimated to be about 950 USD/tonne.

The annual fuel cost for the two high speed vessels today is approximately 4.5 million USD based on the subsidized price. If related to the estimated WCR market price the annual cost would be almost 16.8 million USD, implying an annual fuel subsidy of approximately 12.3 million USD.

It has not been possible to receive an accurate price for natural gas or LNG supplied domestically in Trinidad and Tobago. However, with regard to the proximity of the US market, the Henry Hub prices may be considered as a plausible market price for natural gas in Trinidad and Tobago. At present natural gas is traded at the Henry Hub in the parity of 3.7 USD/MMbtu (Platou, 2013), which corresponds to an approximate price/tonne of 173 USD/tonnes. It is also assumed that a 20% mark-up is necessary to cover the cost of liquefaction, and, consequently, a reasonable price estimation for LNG would be about 208 USD/tonnes.

Table 29 – *Estimated cost of LNG delivered as fuel to the high speed vessels*

Supply chain	Supply chain cost USD/tonne LNG	LNG or NG source price USD/tonnes	LNG price delivered USD/tonnes	Corresponding MDO price USD/tonne
1	51	(LNG) 208	259	306
2a POS	201 (NG) 173	374	442	
2a TOB	224	(NG) 173	397	469
2b	207	(NG) 173	380	449
3	333	(LNG) 208	541	639

Table 29 indicates an estimated cost per tonne of delivered LNG of 259 USD/tonne LNG, if supply chain 1 is selected. Based on the annual estimated consumption for two vessel of 22 000 tonnes as described in section 3.4, the annual fuel cost would then be 5.7 million USD without any governmental fuel price subsidies.

Compared with the present situation, the introduction of LNG as fuel for the high speed ferry service would increase the annual fuel cost by 1.2 million USD per year if related to the subsidized price. If related to the market price of MDO, the annual fuel cost would be reduced by about 11 million USD per year.

7
Results and recommendations

The TTIT high speed ferry services between Port of Spain and Scarborough are considered a national interest and the cost is subject to financial support from the government of Trinidad and Tobago. The numbers of travellers and vehicles are increasing and the government, PATT and TTIT are eager to develop and modernize the services in a way in which improved environmental performance and reduced emissions can be combined with low fares and low operational costs.

7.1 Cost for reconstruction or newbuilding

The transition from traditional bunker fuel oil to LNG as fuel for the high speed ferries will reduce harmful exhaust emissions significantly and may in the long run also implicate reduced total governmental cost for the ferry services. The report shows that such a transition to LNG fuel is associated with high investment costs for reconstruction of existing high speed ferries or for design and procurement of new LNG fuelled vessels. Reconstruction of the 11-year-old **T&T SPIRIT** is estimated to approximately 32 million USD and an LNG fuelled newbuilding of corresponding capacity may be purchased at a cost of about 100 to 110 million USD. The 16-year-old **T&T EXPRESS** is anticipated to be in need of replacement within about five years, and is, therefore, not considered to be of interest with respect to modification for LNG fuel.

Today there are no applicable regulations in force for the conversion of the existing high speed vessels or for new construction of high speed vessels. Consequently it is formally up to the competent authority of the flag State to decide which rules, regulations, guidelines and standards should be applied for any conversion or newbuilding project as long the vessels operate domestically.

Fortunately, the lack of rules and regulations in force is not considered a show-stopper since there are already a number of internationally recognized guidelines and codes that may be applied. It is important to understand that the situation calls for particularly close cooperation and dialogue among the developer, the competent authority and the classification society to ensure a smooth process and an efficient and safe vessel.

7.2 Supply chain cost and fuel price comparison

If the investments indicated above will be profitable and how long the payback time will be, is of course dependent on operational costs and if the improved environmental performances are evaluated in monetary terms and taken into account in the cost calculations. With regard to the operational cost and specifically the fuel cost, it is noted in the study that due to governmental subsidies of the MDO price the government in fact may save money if the oil consumption of the ferries is reduced and the corresponding amount of oil is exported to world market prices. Regarding the cost for the alternative LNG fuel, the price and operational costs are basically determined by the following three components: the price of natural gas or LNG at the source, the cost of the LNG supply chain and the specific energy consumption and efficiency of the new or reconstructed ship.

The gas price or LNG price at the source is not subject to detailed analyses or estimation in this study. The fact that the hub market price in this region is low and that the government, via state owned gas and pipeline companies, has access to natural gas resources and co-ownership in LNG plants, however, implicate favourable pricing conditions.

Regarding the supply cost chain component, three basic options for feasible LNG supply chains have been identified and analysed, including transportation of LNG by truck from source to the bunkering site at the ferry terminal (No. 1), dedicated small-scale liquefaction plant near the ferry terminal (No. 2a and 2 b) and a supply by LNG bunker barge from the source to the receiving high speed ferry (No. 3).

The three analysed options represent different capacities and different levels of investment costs in facilities and equipment. If the total supply chain costs are distributed over the potential capacities for the respective options, the large-scale systems may offer a more attractive cost per tonne of supplied LNG. If the total supply chain costs have to be distributed over the predicted LNG fuel consumption of the TTIT fleet of high speed ferries only, the cost per tonne of supplied LNG will, however, be very high for the large-scale bunker barge based option (No. 3). In this option the cost for a new small-scale export jetty at Atlantic LNG in Point Fortin is the dominating component, and if the TTIT ferry services is the only user of such a facility, it means that it is underutilized.

For the small-scale option (No. 1) based on TTS bunkering the analysis shows that the cost per tonne of supplied LNG may be attractive and possibly even competitive with today's low subsidized MDO price even if the total supply cost is distributed over TTIT's predicted LNG consumption only.

If today's subsidies of the fuel oil are considered and the potential for reducing the governmental oil subsidy expenditures by transition to LNG fuel is taken into account in the cost comparison by instead comparing the estimated LNG price for the respective supply chain options with today's world market MDO price, all of the three options turn out favourable compared with MDO.

The range of estimated total LNG price delivered to the ferry terminal for the three supply chain options differs a factor 2 when the costs are distributed over TTIT's predicted consumption only. Capacity wise, the bunker barge option (No. 3) offers possibilities for the supply of LNG fuel to more ships in Port of Spain and the jetty may also generate new export potentials for LNG by small and medium size LNG feeder carriers to other countries within the WCR for electricity production and fuel. Such a market development and increasing demand was described and predicted in the Feasibility study conducted in 2012 (SSPA, 2012) and may reduce the supply chain cost component of the LNG delivered to the ferry terminal significantly. If an investment partner willing to cover the initial investment cost of a small-scale export facility from Atlantic LNG in Point Fortin can be identified, this supply chain option (No. 3) is considered to combine favourable supply chain costs, safe bunkering solutions and high flexibility for TTIT's LNG demand and it may also contribute to making Trinidad and Tobago a pioneer for small-scale exportation of LNG in the WCR.

The supply chain options with local small-scale liquefaction plants (No. 2a and 2b) may also be designed preferably for a capacity larger than the actual estimated LNG demand of the TTIT high speed ferries. Such an overcapacity is not expected to increase the cost proportionally but will instead offer possibilities for development of new domestic LNG utilization for local industrial purposes, ship fuel or vehicle fuel. Complementary production and distribution of LNG from the small plants will thus contribute to a reduction of the supply chain costs of ferry fuel and also contribute to environmental improvements if the surplus LNG production is replacing fuel oil of other energy consumers.

Local small-scale production facilities in both the sister islands Trinidad and Tobago, may contribute developing new business in Tobago and if LNG bunkering services are offered in both Port of Spain and in Tobago this means increased flexibility and a potential for less bulky LNG tanks in the ships.

The TTS bunkering concept and supply chain (No. 1) also offers high flexibility, but solutions based on only one LNG tank truck will become sensitive in terms of traffic problems or technical failures.

7.3 Safety considerations

All three LNG bunkering and supply chain options have been initially analysed and compared but additional detailed quantitative analysis will be required during the detailed design phase when hose dimensions, flow rate, pressure of the LNG bunkering system, etc. are specified.

Due to the complicated traffic situation, limited space and adjacent activities and buildings in the Port of Spain ferry terminal, it is not recommended to arrange ITPS facilities for LNG bunkering given the present terminal layout.

TTS LNG bunkering may be possible without passengers on board and without cargo or passenger handling in the berth area, but TTS LNG bunkering with passengers on board or simultaneous cargo handling is not recommended with the present terminal layout.

In Scarborough the ferry terminal is larger, with the passenger and vehicle flows separated from quay areas amidships port side where LNG bunkering operations TTS or ITPS are considered to be possible with or without passengers on board.

STS LNG bunkering options may involve larger flow rates than TTS, but it is generally considered less difficult because mooring a bunker barge alongside the ship may often ensure safe separation distances from the bunkering safety zone and passenger and cargo handling areas.

7.4 Further studies and other pilot applications

The presented pilot study provides important background data for further elaboration of detailed business case studies for future high speed ferry services of TTIT. The study shows that there are good prospects for finding solutions that combine the reduction of harmful exhaust emissions, high safety and reliability with reduction of the overall operational costs seen from a national perspective by transition to LNG as fuel.

Initial costs are relatively high and investment strategies must include considerations on long term potential of an expanding market for small-scale domestic demand and medium scale regional export of LNG for energy production. The LNG fuel cost depends on the selected supply chain and is thereby also highly influenced by the long term strategies and market prospects for future LNG demand.

As a possible alternative to conversion of TTIT's existing high speed ferries for LNG by replacement of the diesel engines to gas turbines, procurement of a second hand gas turbine propelled diesel fuelled high speed ferry, may offer a cheaper solution. Conversion of gas turbine machinery from diesel to LNG is expected to be less complicated than replacement of engines and there are diesel fuelled gas turbine propelled high speed ferries laid up and for sale.

This pilot study may also provide guidance for other stakeholders and member States investigating how to adapt to future stricter emission rates and how to assess the technical and economic prospects for transition to LNG as ship fuel. The initial assumption of this pilot study that the large existing liquefaction plant would provide the obvious source of LNG fuel supply, turned out to be somewhat unexpected. Both technical and business related issues were identified and other sources and local small-scale liquefaction plant were also identified as feasible options. This experience and the width of the presented fuel cost dependency on source and choice of supply chain, highlight the importance of careful supply chain assessment and securing of long term LNG delivery services. For existing LNG fuelled ferry pilot projects, cf. appendix 3, well-established cooperation between the ferry operator, the ship designer, the LNG supplier, the port and the regulating authorities at an early project stage have proven to be key factors for success.

TRINIDAD AND TOBAGO

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Appendix 1

Pilot study on the use of LNG as a fuel for a high speed passenger ship from the Port of Spain ferry terminal in Trinidad and Tobago

Site visits and project meetings conducted by the consultant team

Project inception phase

The contract between IMO and SSPA Sweden was signed 26 June 2013. White Smoke Consulting and Light Craft Design Group LDG were contracted as sub-consultants to SSPA. The ToR of the contract stipulate a draft report to be delivered by 22 November and a final report by 20 December 2013. Information was initially collected and communicated by correspondence with local counterparts and stakeholders.

On September 5 a teleconference call was held with two representatives from TTIT, two representatives from the consultant team, one IMO Consultant, Liaison/facilitator and one Regional IMO Maritime Adviser in Trinidad and Tobago. At the teleconference, important contact persons and organizations were identified and a preliminary schedule for visits was outlined.

Meetings and workshop in Trinidad and Tobago in September 2013

On September 16 Björn Forsman, SSPA and Johan Algell, White Smoke from the consultant team had a preparatory meeting with Mr Leon Grant, CEO TTIT and Ms Josanne Phillips, Executive Secretary to CEO, TTIT.

On September 17 a meeting was arranged with Mr Colin Young, IMO Regional Maritime Adviser, the TTIT representatives and a tour in the terminal area was arranged. The tour showed that the ferry terminal area has limited space for waiting vehicles and cargo. An onboard visit and presentation of the **T&T SPIRIT** was also arranged and guided by expertise from the technical management operator, Bay Ferries Ltd. The purpose was to survey the possibilities to convert the vessel for the use of LNG as fuel including LNG tank location and engine room reconstruction. The **T&T EXPRESS** was temporarily out of service but considered too old to be subject for detailed LNG reconstruction considerations.

On September 18 a workshop for presentation of the study and identification of key issues was arranged and hosted by TTIT and PATT. The workshop attracted 29 attendees representing different stakeholders as, TTIT, Maritime Service Division, NIDCO, Atlantic LNG, DNV, Min. of Energy, Min. of Transport, National Energy Corporation, National Gas Company, etc.

The workshop focused on various options for the LNG supply chain and associated safety issues. Regarding possible use of tank trucks for LNG supply and bunkering, safety and reliability concerns were pointed out regarding the traffic situation both locally in Port of Spain and along the existing road from Atlantic LNG in Point Fortin. Atlantic does not have facilities for truck loading nor for loading of small LNG barges and there are presently no plans for development of such facilities. NIDCO reported that an on-going road development programme includes upgrading of the road between Port of Spain and Point Fortin scheduled for completion in March 2015. After the workshop, the project partners summarized the meeting and agreed on additional meetings with dedicated organizations and a timetable for the next site visit in Trinidad and Tobago. A progress report was submitted to IMO, London.

On September 19 an onboard visit and demonstration was conducted in one of NIDCO's water taxi vessels. Available space for possible placing of LNG tanks was found limited and the engine rooms also have limited space to accommodate modified or replacement engines for LNG fuel.

On September 20 two meetings were arranged with the National Energy Corporation (NEC) and the National Gas Company (NGC) in Couva. NEC described ongoing discussion on the possibilities to establish a small/mid-scale LNG production facility in the La Brea area with a capacity of approximately 0.4 MMpta. If established, such a facility could also include a small-scale export jetty and facilities for LNG loading of trucks and containers. NGC owns TTLNG who owns 11% of Atlantic LNG train IV and in two years the contracts may be renegotiated and possibly allow domestic utilization of a minor portion of the LNG production.

Analysis phase – Compilation and analysis of information

Collected information was compiled and analysed according to the outlined project structure and a draft report was prepared. Additional information was retrieved from various local contact persons and stakeholders.

Meetings in Trinidad and Tobago in November 2013

On November 14 the consultants arrived in Port of Spain and took the **T&T EXPRESS** to Tobago for a presentation and meeting in the ferry terminal in Scarborough. A courtesy call to the Chief Secretary of Tobago house of assembly was also conducted with a short presentation and discussion. The Chief Secretary supported the project for further consideration and appreciated being informed at an early stage of the project.

On November 17 SSPA's consultants made a presentation for a group of 19 stakeholders and representatives from PATT, TTIT, POSINCO, IMO, Maritime Services Division, Min. of Energy, Min. of Transport and NEC. The meeting was followed by productive discussions. The presented output of the study was considered relevant and useful and it was confirmed that a draft report would be delivered to IMO and TTIT on November 22. A short progress update was submitted to IMO, London.

Delivery of draft report

A draft report was submitted on November 22 to IMO, London, and to TTIT and the project representatives including IMO's regional advisor and project liaison facilitator. Comments on the draft were received on November 29 and have been taken into account in the final version of the pilot study report.

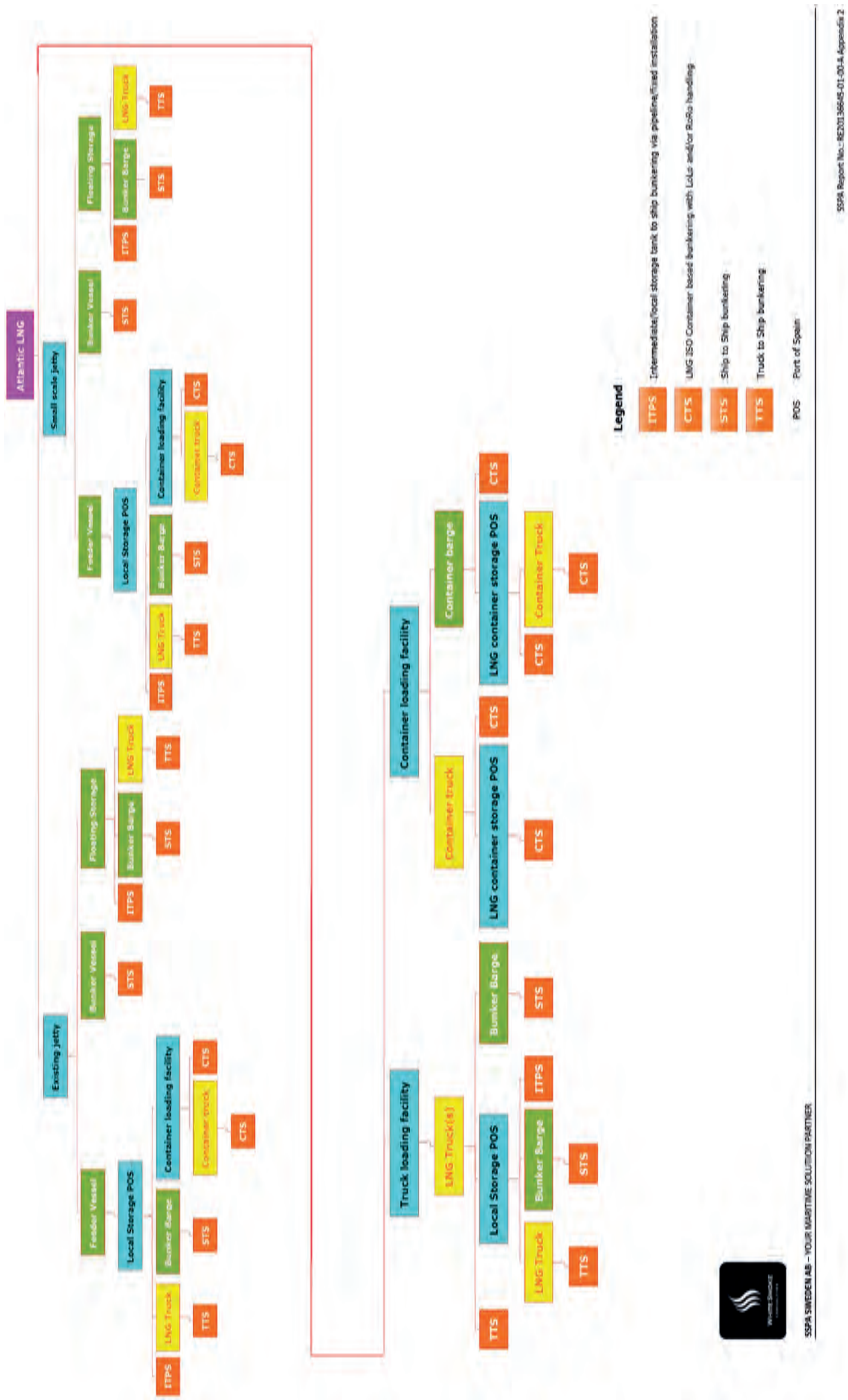
Delivery of final report

The final report was submitted on December 20.

Appendix 2

Pilot study on the use of LNG as a fuel for a high speed passenger ship from the Port of Spain ferry terminal in Trinidad and Tobago

General LNG supply chain options, box chart



Appendix 3
Pilot study on the use of LNG as a fuel for a high speed passenger ship from the Port of Spain ferry terminal in Trinidad and Tobago

Examples and experience of LNG bunkering of ferries

Outside Norway there are presently only a few LNG fuelled passenger ferries in operation. Between Sweden and Finland a large LNG fuelled ro-ro/passenger ferry entered into operation in January 2013 and the first large-scale LNG fuelled high speed ferry is about to enter into operation between Argentina and Uruguay. The ferries have different types of engines, dual fuel, pure gas engines and dual fuel gas turbines, and all three basic bunkering concepts are represented; ship to ship, truck to ship, intermediate tank via pipeline to ship. For most of the ferries LNG bunkering is conducted night-time without passengers on board but some ferries are regularly bunkering with passengers on board. Some examples of LNG fuelled ferries are briefly described below.

GLUTRA, Norway

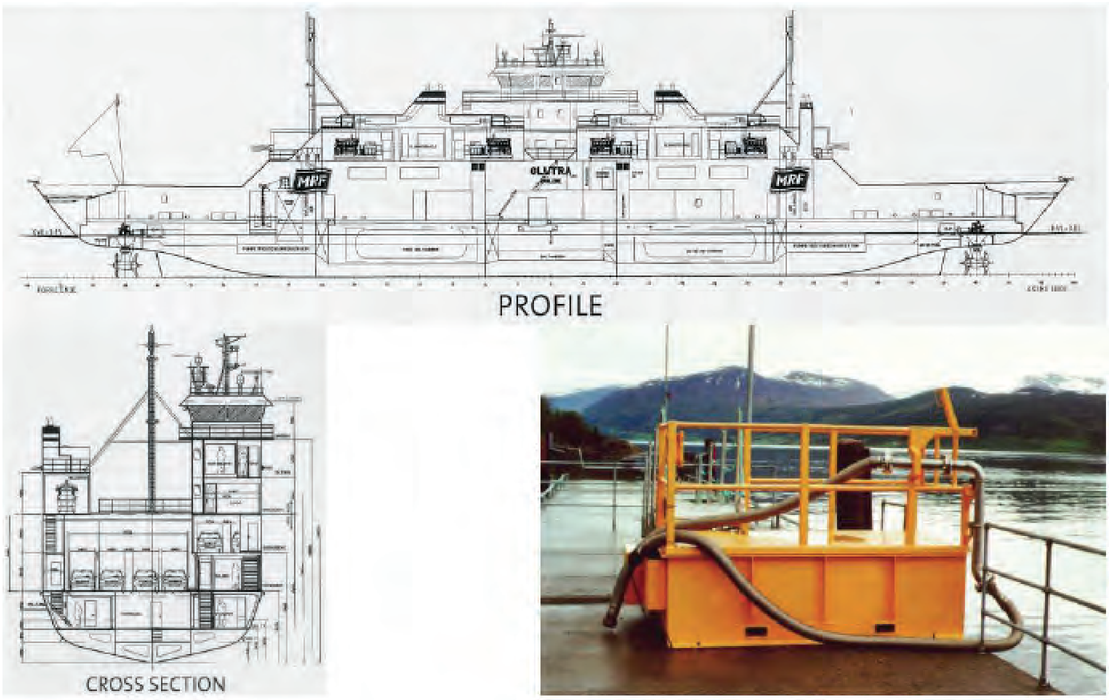


Figure 1: *The first LNG fuelled ferry, the Norwegian ferry **GLUTRA**. Profile and section of **GLUTRA**, engine room top left and refuelling bridge (Stokholm & Roaldsøy, 2000)*

Table 1 – *Data on Norwegian LNG fuelled ferry **GLUTRA***

Start of operation	2000	LNG tank type/capacity	2 × 27 m^3 vacuum/perlite C-tanks
Route	Flakk–Rørvik, Trondheim	LNG bunkering concept	Tank truck
Length, L	95 m	LNG Bunkering rate/time	2 hours, Every 6 day
Passengers	300	Bunkering conditions	Night-time, no passengers
Cars	96 or (42 + 8 trailers)	Ref	(Stokholm & Roaldsøy, 2000)

FJORD1, Norway

The Norwegian shipowner Fjord1 operates a large number of road ferries in Norway and started operating LNG fuelled vessels in 2007. The vessels are STAVANGERFJORD, **FANAFJORD**, **MASTRAFJORD**, **BERGENSFJORD** and **RAUNEFJORD** designed with gas only engines and ESD engine room concept. They are bunkered without passengers from land based intermediate storage tanks supplied LNG by trucks.

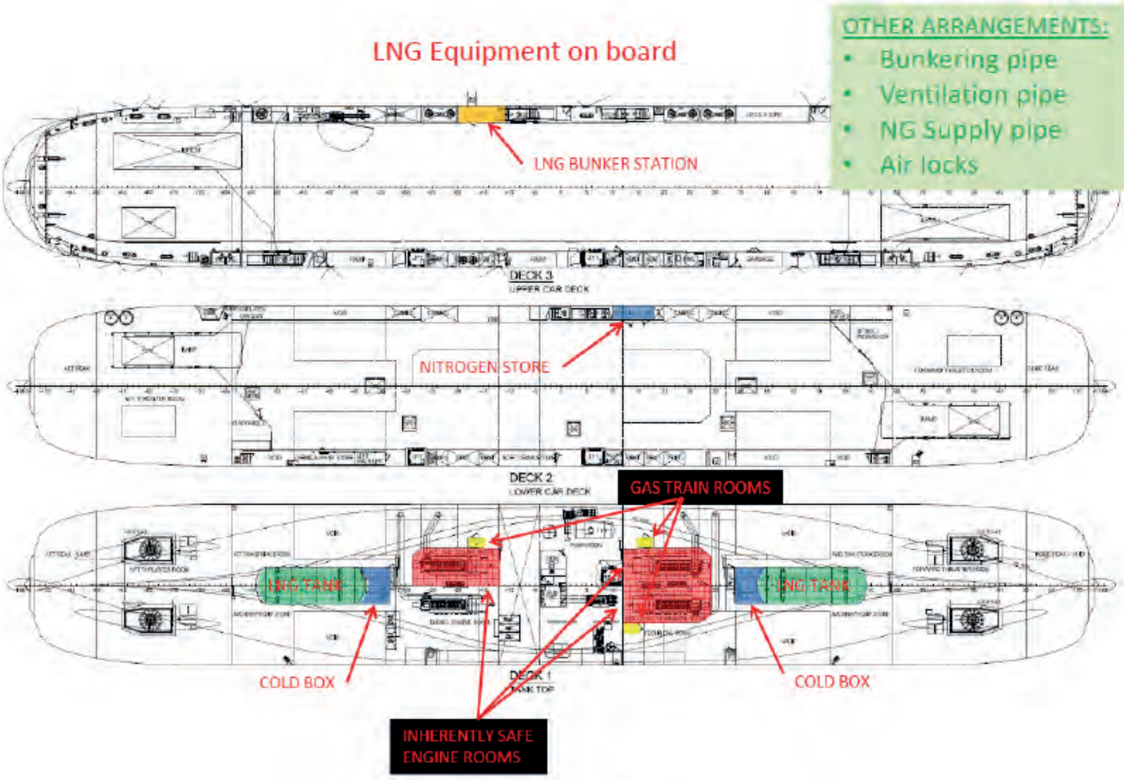


Figure 2: *Fjord1 LNG fuelled ferries – LNG equipment on board and inherently safe engine rooms (Petrov, 2013)*

Fjord1's **BOKNAFJORD** is one of three sister ships representing a newer larger generation of LNG fuelled road ferries that has been in service since 2011.

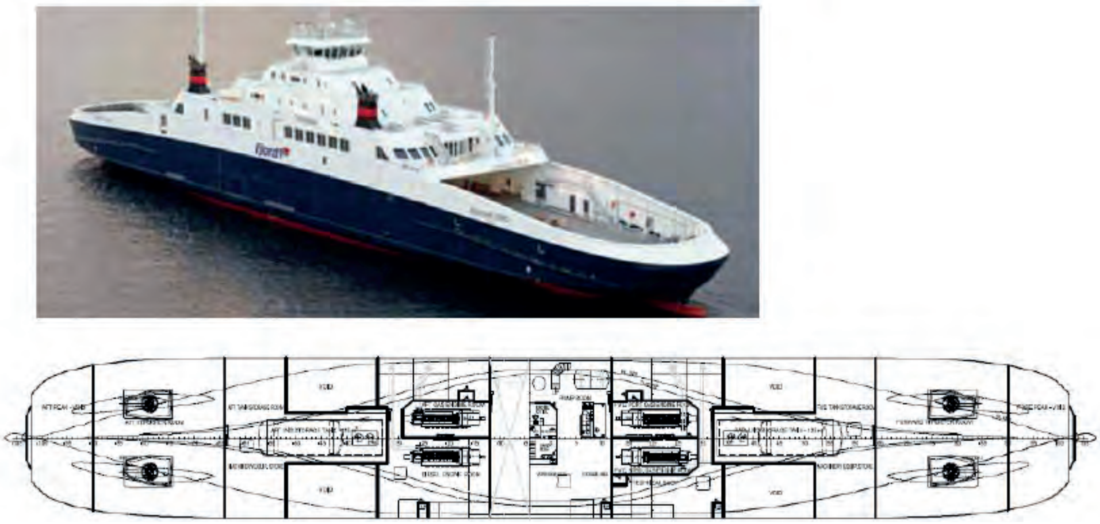


Figure 3: ***BOKNAFJORD** layout (Hoel, 2013) engine control system (Rolls Royce, 2012) (Photograph reproduced courtesy of Karl Otto Kristiansen)*

Table 2 – *Data on* ***BOKNAFJORD***

BOKNAFJORD particulars		**LNG bunkering data**	
Start of operation	2011	LNG tank type/capacity	2 × 125 m^3 vacuum/perlite C-tanks
Route	Fjord crossings	LNG bunkering concept	Pipeline from land base intermediate storage tank supplied by tank truck
Length, L	130 m	LNG Bunkering rate/time	3 hours, once a week
Passengers 589 Bunkering conditions	Night-time, no passengers		
Cars	242	Ref	(Rolls Royce, 2012)

TIDEKONGEN, Norway

TIDEKONGEN is one of three sister ferries with dual fuel engines operating in the capital Oslo.

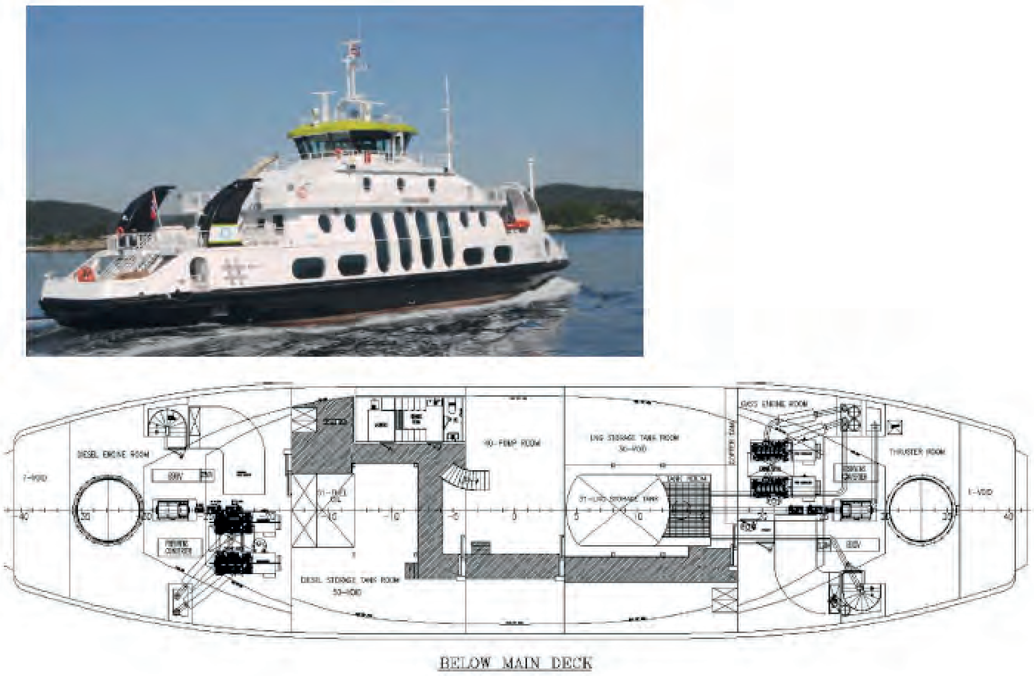


Figure 4: ***TIDEKONGEN***, *tank and engine arrangement (Grimstad Osberg, 2013)*

Table 3 – *Data on Tidekongen*

Tidekongen particulars		**LNG bunkering data**	
Start of operation	2009	LNG tank type/capacity	50 m^3
Route	Oslo – Nesodden	LNG bunkering concept	by truck and 7 m hose
Length, L	50 m	LNG Bunkering rate/time	Twice a week, 1–2 h, 40 m^3/h
Passengers	628	Bunkering conditions	Night-time, no passengers on board
Cars	–		

Vestfjorden ferries, Torghatten Nord

TORGHATTEN NORD represents the first of the five LNG fuelled sister vessels LNG, **LANDEGODE**, **VÆRØY**, **BARØY** and **LØDINGEN**.

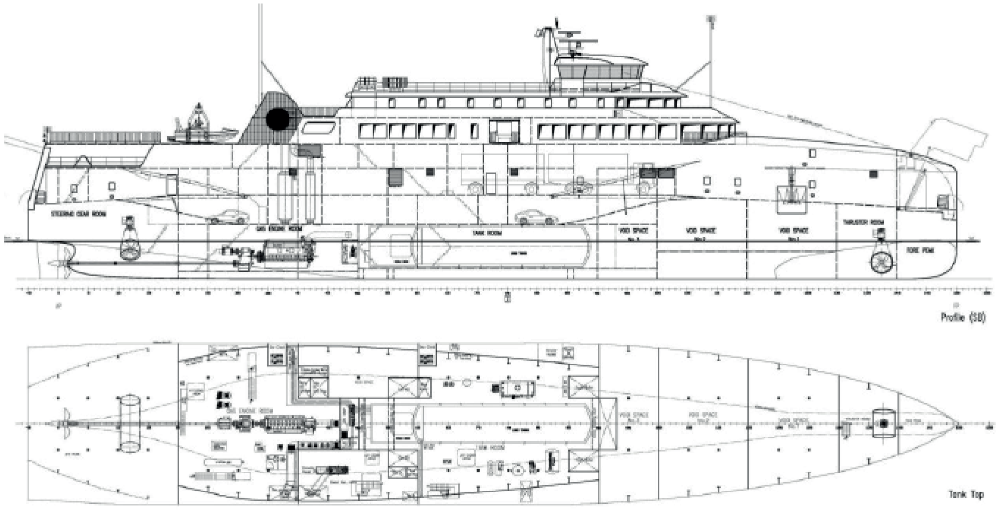


Figure 5: ***TORGHATTEN**, Nord ferries*

Table 4 – *Data on **TORGHATTEN***

TORGHATTEN particulars		LNG bunkering data	
Start of operation	2012	LNG tank type/capacity	150 m^3
Route	Lödingen, N Norway	LNG bunkering concept	ITPS from land based tank (250 m^3) supplied by LNG truck
Length, L	93 m	LNG Bunkering rate/time	150 m^3/h/1½ h
Passengers	390	Bunkering conditions	Night-time, no passengers on board
Cars	120 + 12 trailers		

FJORDLINE, Norway

FjordLine took delivery of the LNG fuelled RoPax vessel **STAVANGERFJORD** in 2013 and the sister ship Bergensfjord will be delivered later this year for operation between Norway and Denmark. The Norwegian authorities initially did not allow LNG bunkering from truck with passengers on board awaiting the finalization of a permanent quay based fixed loading arm at the berth in Norway. The long term bunkering solution includes bunkering via a loading arm supplied from a 600 m long 6 inch vacuum insulated LNG pipeline from a FBT LNG storage tank located near the ferry terminal. The engines are not dual fuel type, operates with LNG only.

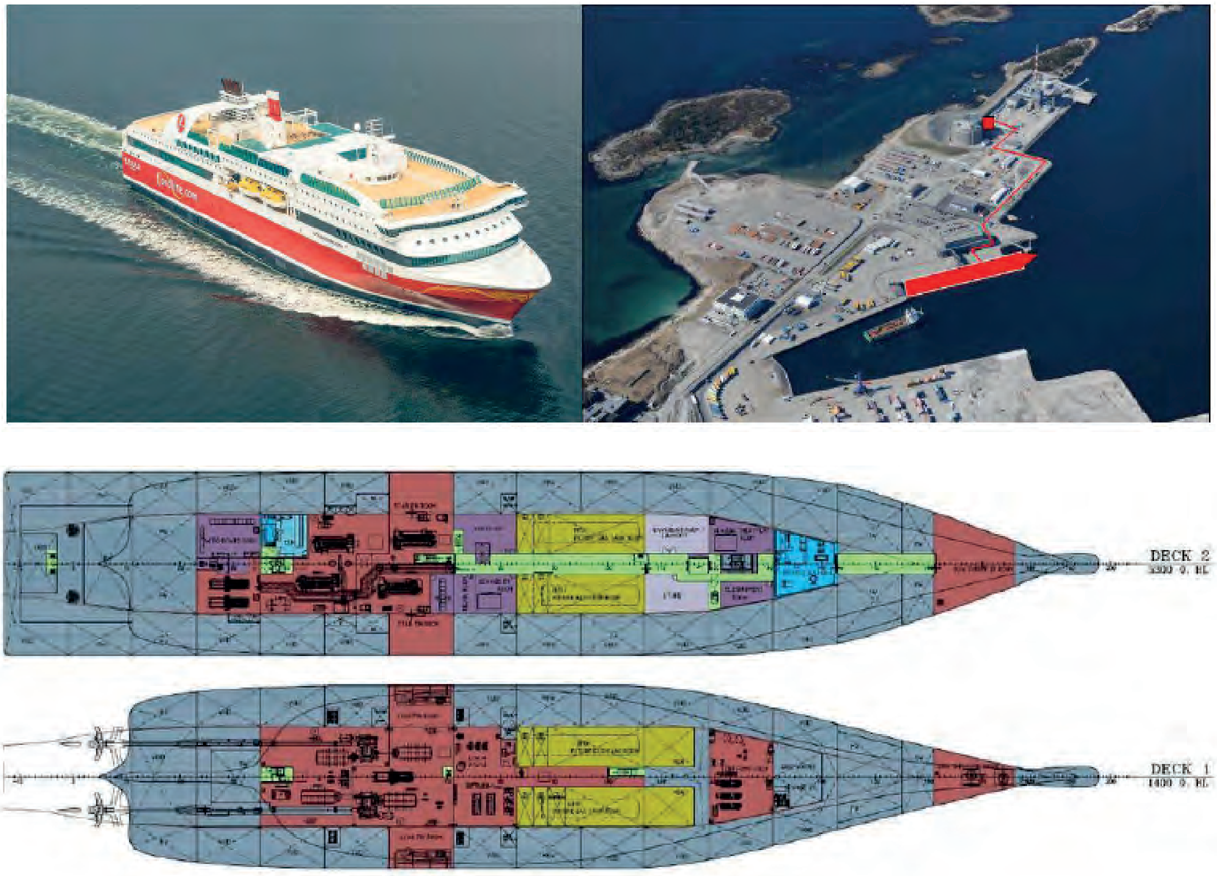


Figure 6: *Terminal with LNG pipeline for bunkering of Fjordline's **STAVANGERFJORD** and engine room and LNG tank arrangement (Blomberg, 2013) Photographs reproduced courtesy of Espen Gees (Fjordline))*

Table 5 – *Data on **STAVANGERFJORD***

STAVANGERFJORD particulars		**LNG bunkering data**	
Start of operation	2013	LNG tank type/capacity	2 × 296 m^3 tanks
Route	Bergen-Stavanger		
NO – Hirtshals DK	LNG bunkering concept Pipeline from land based FBT, to loading	Arm at berth, no hoses, no vapour return	
Length, L	170 m	LNG Bunkering rate/time	Max 330 m^3/h at 8–10 bar
Passengers	1500	Bunkering conditions	Temporarily by LNG trucks. Long term by dedicated fixed loading arm at the berth
Cars	600	Ref	(Rolls Royce, 2012)

VIKING GRACE, Finland

VIKING GRACE was the first LNG fuelled large ropax ferry and the first to bunker ship-to ship. It operates between Sweden and Finland and has dual fuel engines with the LNG tanks located in the aft deck. The LNG bunker is supplied by a dedicated self-propelled bunker barge in Stockholm, mooring alongside the vessel. The LNG is transferred by pressure difference without pumping. The bunker barge is filled from tank trucks at another berth in the port of Stockholm.

Figure 7: *VIKING GRACE and the LNG bunker barge moored alongside at the ferry's bunker station. Engine and propulsion arrangement (Granberg, 2013)*

Table 6 – *Data on **VIKING GRACE***

VIKING GRACE particulars		**LNG bunkering data**	
Start of operation	2013	LNG tank type/capacity	2 × 200 m^3 vacuum insulated type C
Route	Stockholm SE – Turku FI	LNG bunkering concept	Ship to ship, 6 inch hose, no vapour return
Length, L	218 m	LNG Bunkering rate/time	Max 180 m^3/h, 55 minutes, 5 times/week
Passengers	880 + 200 crew	Bunkering conditions	With passengers on board
Ro-ro Lanemetres	1275 + 550 +550		

Figure 8: *Ship-to-ship LNG bunkering from the LNG bunker barge **SEAGAS** to **VIKING GRACE***

HSC FRANCISCO, Uruguay

The 99 m long **HSC FRANCISCO** is the first LNG fuelled high speed ferry. The operator Buquebus in Argentina took delivery from InCat Australia in July 2013 and intends to start operating it with LNG fuel produced by its own small-scale liquefaction plant from December 2013. Two dual fuel 22 MW GE LM2500 gas turbines driving Wartsila LJX 1720 SR waterjets allow an operating speed of 50 knots and maximum speed 58 knots. Six Cryobox nano LNG units will ensure production to meet the daily demand of 84 m^3.

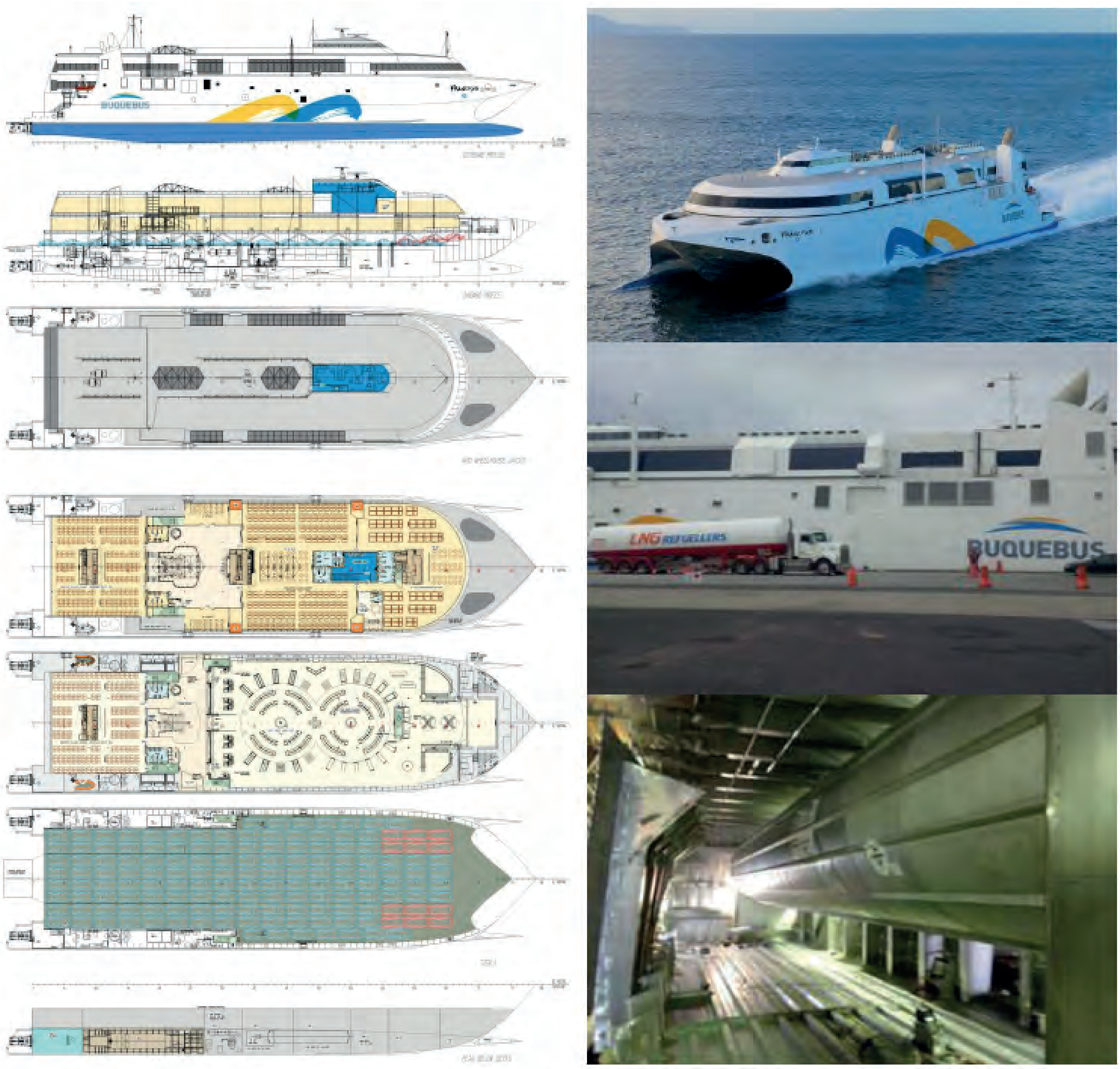


Figure 9: ***HSC FRANCISCO*** *(Incat, 2013), general arrangement, first fuelling in Australia and LNG tank*

Table 7 – *Data on InCat No. 069 Francisco*

FRANCISCO particulars		LNG bunkering data	
Start of operation	2013	LNG tank type/capacity	2 × 40 m^3 LNG, 2 × 70 m^3 fuel oil
Route	Buenos Aires – Montevideo	LNG bunkering concept	By truck at the ferry berth. LNG from local small-scale liquefaction units
Length, L	99 m	Bunkering conditions	Night-time, no passengers on board
Passengers/cars	1000/150		

Feasibility Study on LNG Fuelled Short Sea and Coastal Shipping in the Wider Caribbean Region

Contents

List of abbreviations and acronyms

CNG	Compressed Natural Gas
dwt	Dead Weight Tonnage (tot weight of a ship's cargo, fuel, etc.)
ECA	Emission Control Area
ESD	Emergency Shut Down
FEED	Front End Engineering Design
FLRSU	Floating Liquefaction, Regasification and Storage Unit
FLSO	Floating Liquefaction Storage Offloading vessel
FOB	Free On Board (with regard to bunker prices)
FOC	Fuel Oil Consumption
FSRU	Floating Storage and Regasification Unit
GT	Gross Tonnage (an index of ship's overall internal volume)
HFO	Heavy Fuel Oil
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
IGF	International Code of Safety for Ships using Gases or other Low Flashpoint Fuels (IGF Code)
IMO	International Maritime Organization (www.imo.org)
ISO	International Organization for Standardization
LFL	Lower Flammability Level
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MARPOL	International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto
MGO	Marine Gas Oil
MMBtu	Million British Thermal Unit, 1 MMBtu = 293 kWh = 1.055 MJ
OSV	Offshore Supply Vessel (often used in the US instead of PSV)
PSV	Platform Supply Vessel
SIGTTO	Society of International Gas Tanker and Terminal Operators
RAC REMPEITC	Regional Activity Centre, Regional Marine Pollution Emergency Information and Training Centre
TPS	Bunkering from storage Tank via Pipeline to Ship
STS	Ship To Ship (LNG bunkering concept)
TTS	Truck To Ship (LNG bunkering concept)
UFL	Upper Flammability Level

Terms and definitions

Term	Definition
AIS	Automatic Identification System is a very high frequency (VHF) radio-based system, which enables the identification of the name, position, course, speed, draught and cargo of ships.
WCR	Wider Caribbean Region, referring to the area covered by the RAC/REMPEITC-Caribe, is the Cartagena Convention area, which represents the marine environment of the Gulf of Mexico, the Caribbean Sea and the areas of the Atlantic Ocean adjacent thereto, south of 30 degrees north latitude and within 200 nautical miles of the Atlantic coasts of the States referred to in Article 25 of the Convention. Countries include: Antigua and Barbuda, Bahamas, Barbados, Belize, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, France, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Kingdom of the Netherlands, Nicaragua, Panama, St Kitts and Nevis, Saint Lucia, St Vincent and the Grenadines, Suriname, Trinidad and Tobago, United Kingdom, United States of America and Venezuela.
International shipping	Shipping between ports of different countries, as opposed to domestic shipping. International shipping excludes military and fishing vessels. By this definition, the same ship may frequently be engaged in both international and domestic shipping operations (IPCC 2006 Guidelines).
Domestic shipping	Shipping between ports within one country.
Coastwise shipping	Coastwise shipping is freight movements and other shipping activities that are predominantly along coastlines or regionally bound (e.g. passenger vessels, ferries, offshore vessels) as opposed to ocean going shipping. The distinction is made for the purpose of scenario modelling and is based on ship types, i.e. a ship is either a coastwise or an ocean going ship.
Short sea shipping (Short sea shipping in project ToR)	Short sea shipping includes domestic and international maritime transport, including feeder services, along the coast and to and from the islands, rivers and lakes. Short sea shipping includes dom-estic and international maritime transport, including feeder services, along the coast and to and from the islands, rivers and lakes. Typical short sea ship size ranges from 1 000 – 15 000 dwt. Typical short sea ship size ranges from 1 000 – 15 000 dwt.

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Summary

In August 2012 the North American ECA came into force; in January 2014 the US Caribbean ECA will take effect; and in the future the ECAs in the WCR are anticipated to expand further. There are a few different technical and operational options available to comply with the ECA requirements, and the transition from HFO to LNG fuel is considered an interesting option. IMO therefore contracted SSPA Sweden AB and White Smoke AB to investigate the feasibility of introducing LNG as a ship fuel for short sea and coastal shipping in the WCR.

The report addresses the following main issues and topics:

- Identification of shipping activities in the WCR
- Identification of key trends of shipping activities in the WCR
- Estimation of the potential for LNG as ship fuel in the WCR
- Appraisal of existing LNG infrastructure and future plans
- Identification of key barriers for adopting LNG as ship fuel
- Identification of key enablers for adopting LNG as ship fuel

The following sources were reviewed for information of ship traffic data:

- RAC-REMPEITC Caribe GIS database for maritime traffic in the WCR
- Recorded AIS statistics and
- Statistics from the Panama Canal Authority and other organizations

The shipping segments addressed in the study are categorized as follows:

- Tanker
- General cargo
- Tug and supply
- Bulk
- Passenger
- Other

Ship traffic in the WCR is intensive with more than 100 000 registered port calls per annum. General cargo traffic dominates in the WCR but tanker and passenger traffic are also frequent. Today about 37% of the registered port calls are within the present North American ECA but the US Caribbean ECA will contribute another 9% in 2014.

Today LNG is loaded or unloaded in terminals along the US Gulf Coast, in Trinidad & Tobago and in the mid Caribbean islands of the Dominican Republic and Puerto Rico but a number of new terminals are projected in various places in the WCR. If existing and new LNG terminals are complemented with facilities for truck loading, for loading of bunker vessels or bunkering of LNG fuelled vessels, a basic infrastructure network for distribution and supply of LNG fuel can be established and ensure an attractive LNG FOB bunker price.

In addition to the physical infrastructure for LNG fuel distribution, barriers related to regulative gaps and the lack of technical standards also needs to be addressed. Training and education requirements are another important issue where international cooperation and careful control are needed to minimize the specific hazards associated with the handling of LNG as ship fuel. Public consultation and awareness processes as

well as possible economic incentive schemes also represent important enablers that may facilitate and speed up the introduction of LNG as ship fuel in the WCR.

A number of the identified short sea and coastal shipping segments are considered suitable for introduction of LNG as fuel but not only typical short sea and coastal segments may become early adopters.

Platform support vessels and some specific tug segments are considered suitable for LNG introduction and may become early adopters. New buildings in the cruising segment and container feeder vessels in the WCR are also categories considered suitable with respect to additional cost for LNG supply infrastructure. Another WCR ship segment, which is in contrast to the ones above, not associated with very high conversion costs for introduction of LNG fuel is the tanker segment. The specific ferry service between Trinidad and Tobago islands is also considered a particularly interesting potential pilot route for introduction of LNG as ship fuel.

The introduction of LNG as fuel in these segments is not necessarily to be seen as an ECA compliance strategy for application within ECAs only, but full time LNG operation may also be found economically attractive and environmentally beneficial compared with HFO-MGO swapping strategies. Future possible expansion of the WCR ECAs will provide further incentive for LNG introduction and speed up the adoption rate.

Quantitative examples of possible future LNG demand and costs for required LNG bunker distribution infrastructure, bunker vessels, etc. are presented, indicating that introduction of LNG as ship fuel in the WCR is feasible and that there are good prospects for LNG to become an attractive fuel option for specific ship segments operating in the WCR.

The presented examples together with the general suitability and trend analyses provide a good overview of the possibilities and limitations for introduction of LNG as ship fuel for short sea and coastal shipping in the WCR and the feasibility for establishment of an LNG bunkering infrastructure.

Acknowledgements

SSPA Sweden AB and White Smoke AB acknowledge the Regional Activity Centre, Regional Marine Pollution Emergency Information and Training Centre (RAC-REMPEITC) for access to GIS-based database for maritime traffic in the WCR. Traffic pattern diagrams from the web map application have been derived and are excerpted as figures in the report.

1 Introduction

1.1 Background

The International Maritime Organization (IMO) has a special responsibility for the regulation of international shipping, safety at sea and the prevention of marine pollution.

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of operational or accidental pollution of the marine environment by ships. MARPOL Annex VI, specifically addressing air pollution from ships, entered into force in 2005. The Baltic Sea Sulphur Emission Control Area (SECA) has been in force since 2005, and the North Sea and English Channel SECA came into force in 2007. In August 2012 the North American ECA covering the US coasts and Hawaii came into force and from 2016 the area will encompass NO_x emission control requirements. In January 2014 the US Caribbean ECA covering Puerto Rico and the US Virgin Islands is due to take effect.

Within ECAs, the maximum allowed sulphur content of fuel oil is 1.0 % and after 1 January 2015 the maximum allowed sulphur is 0.1%. Outside ECA 3.5% is allowed until 1 January 2020 (or possibly until 2025)[1] and thereafter 0.5%.

More areas within the Wider Caribbean Region (WCR) will possibly become a future Emission Control Area (ECA) under MARPOL Annex VI. In addition to the decided designations of ECAs some additional areas are also discussed as indicated by the map below.

To prepare for this possible regulatory development, the use of different fuels with less environmental impact needs to be further studied.

There are a few different technical and operational options to comply with the ECA requirements and the transition from HFO to LNG fuel for operation of ships within the ECA is considered an interesting option.

IMO has therefore given SSPA Sweden AB and White Smoke AB the task to further explore the feasibility of LNG as a potential fuel source for short sea and coastal shipping in the WCR.

[1] Depending on the outcome of a review to be completed by 2018

Figure 1: *Decided existing and possible future ECAs. Based on DNV 2011/02*

1.2 Scope and methodology

The scope of this feasibility study of LNG as potential ship fuel in the WCR includes six main components as listed below.

Table 1 – *Components of the feasibility study according to the assignment*

Component	Description
1 Identification of shipping activities	The present shipping activities within the WCR will be identified, looking at ship types, main routes, intensity of traffic, etc.
2 Identification of key trends	The key trends in demand for shipping services in the WCR will be identified and the likelihood and impact of possible future development scenarios will be estimated, one possible scenario being the introduction of ECA in the region.
3 Estimation of potential for LNG	Based on the shipping activities and the key trends identified, the potential ship types and routes in the region for which LNG has significant potential will be identified.
4 Appraisal of LNG Infrastructure	Current and planned infrastructure for LNG in the region will be appraised, giving special focus to availability and costs of the infrastructure needed for LNG introduction.
5 Identification of key barriers to adopting LNG	There are several barriers to the adoption of LNG as fuel for shipping. The key barriers in the WCR will be identified and discussed.
6 Identification of key enablers to adopting LNG	The key enablers to aid adopting LNG and synergies with other developments in the region will be identified.

1.2.1 Geographic coverage

The study covers the Wider Caribbean Region (WCR) comprising the insular and coastal states and territories with coasts on the Caribbean Sea and Gulf of Mexico as well as waters of the Atlantic Ocean adjacent to these states and territories and includes 28 island and continental countries. The figure below shows the area as defined by RAC-REMPEITC Caribe. This definition is consistent with the coverage of the REMPEITC WCR ship movement database, which is used in this report for characterization of the WCR ship traffic.

It may be noted that in MARPOL Annex V (Garbage), the WCR special area does not include Suriname and French Guyana, and its border in the Atlantic Ocean are given by the coordinates: Coast of Florida at; 30N 77 30′W; 20N 59W; 7 20′N 50W; Coast of Guyana.

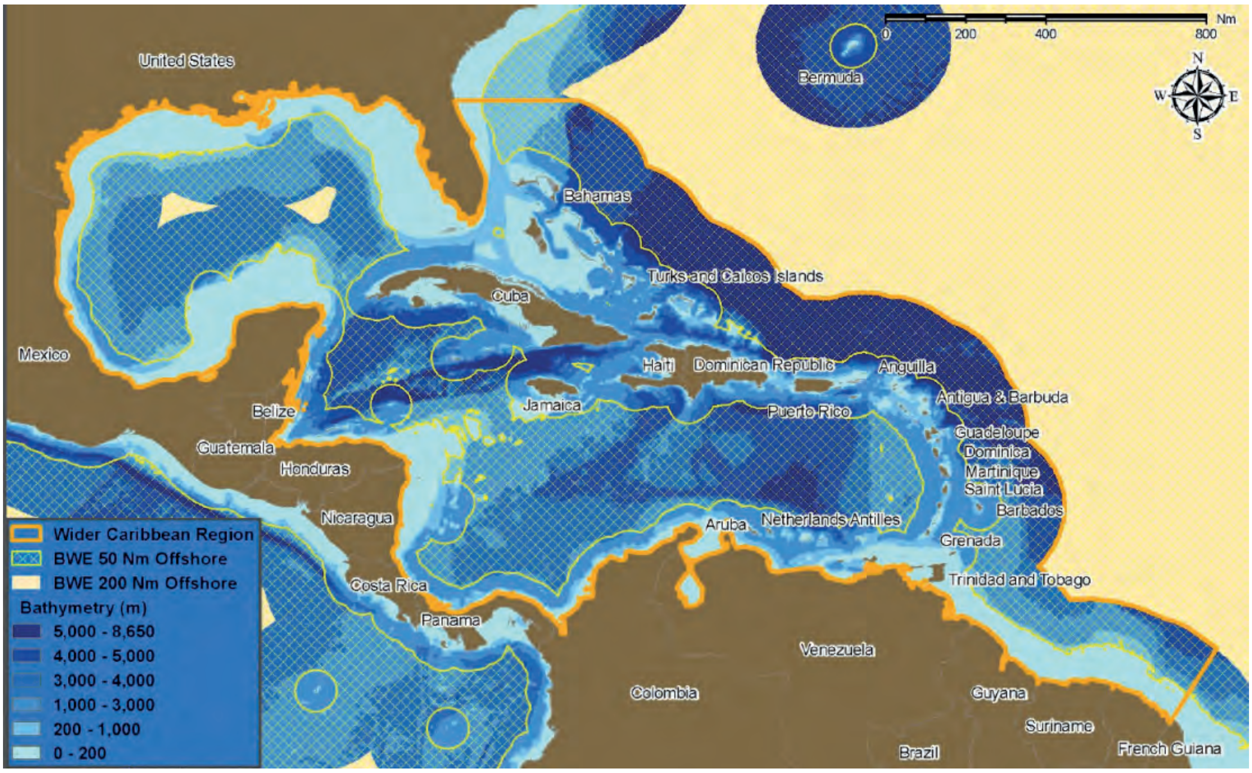

Figure 2: *The Wider Caribbean Region, WCR as defined by RAC-REMPEITC Caribe*

1.2.2 Short sea and coastal shipping

The focus of this study is on short sea and coastal shipping. The term short sea shipping has no established precise definition but the term clearly excludes trans ocean shipping, and inland waterway shipping is traditionally not included in short sea shipping. In Europe, Short Sea Shipping means the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe. Short sea shipping includes domestic and international maritime transport, including feeder services, along the coast and to and from the islands, rivers and lakes. Typical short sea ship size ranges from 1 000 – 15 000 dwt but some are small enough to travel and be engaged on inland waterways. Short sea shipping includes the movements of wet and dry bulk cargoes, containers and passengers.

The distances in the WCR between ports in Texas in the north and in Trinidad & Tobago in the south are comparable to those between European ports in Finland and Italy. With a broad definition of the WCR short sea shipping, it includes movement of cargo and passengers by sea between ports situated in the WCR, coastal shipping along the mainland coasts, along the large islands and between the small islands. In this report the term "internal WCR ship traffic" is also used to denote this traffic and to separate it from ship traffic entering or leaving WCR ports from ports outside the WCR, denoted "WCR external traffic".

2
Shipping in the Wider Caribbean Region

2.1 Basic shipping characteristics in the WCR

The WCR is a busy shipping area representing a wide range of different shipping segments, different commodities and ship sizes engaged in inter-ocean routes as well as regional short sea, coastal and inter-island traffic. Extensive offshore operations and cruising activities contribute to making the shipping situation very complex.

A number of major global shipping routes primarily pass through the WCR area. These routes, primarily running in an east-west direction, are related to traffic passing through the Panama Canal. Some of the vessels trading in these routes are calling ports within the WCR but most of them only transit through the area without any stop over.

Another major route is the north-south trade route related mainly to the energy trade between North and South America. This route is related to the oil and gas resources available in the Northern part of South America feeding primarily the US market with energy.

In addition to the oil and gas sources in the southern part of the WCR there are also significant oil and gas resources in the Mexican gulf. Both these areas generate a lot of ship traffic related to the exploration, production and transportation of oil and gas; in addition to the necessary tanker operations there are also a lot of PSV, anchor handlers, construction vessels, seismic exploration vessels, etc. operating within these areas.

Traditionally the backbone of the intra-regional ship transport system in the WCR has been supplied by small-scale artisanal vessels, shipping all kinds of cargo such as passengers, agricultural products, consumer goods, energy, chemicals, wood products, machinery, construction material, etc. This kind of shipping is gradually replaced by bigger ships, handling of containerized cargo, etc.

Another significant shipping segment is the cruise industry. According to Florida-Caribbean Cruise Association (FCCA 2012) almost 40% of all global cruise capacity operates in the Bahamas/Caribbean region but the cruise activity is also significant in other parts of the WCR.

With regard to possible future extended ECA requirements in the WCR and the potential for LNG as ship fuel, the WCR internal traffic is more interesting than the transit traffic through WCR and other external WCR traffic only spending part of its operation time in the WCR. Ship operators whose vessels basically are operating outside ECAs are assumed to be less prone to change to LNG fuel.

The portion of the WCR traffic that is specifically serving and calling US ports are subject to the Merchant Marine Act from 1920. This act, known as the Jones Act, has a significant impact on the shipping in the WCR basically stating that any vessel trading between two US ports has to fulfil a number of criteria such as:

- Being built in the US
- Being owned by a US company/US citizens
- Being crewed by US citizens
- Flying the US flag

From a commercial perspective the Act has created a closed market for vessels only trading between US ports. The cost levels for these vessels are significantly higher than for equal vessels in international trade. Provided the act remains unchanged the market for these vessels is more predictable and less competitive than for the international markets.

2.2 Available data on ship traffic statistics and route pattern

A number of various sources have been reviewed in order to find information on the ship traffic pattern, the main routes, ports and traffic intensity in the WCR. The sources considered most useful were the following:

- RAC-REMPEITC Caribe GIS-based database for maritime traffic in the WCR
- Recorded AIS statistics
- Statistics from the Panama Canal Authority and other regional and port agencies

Detailed information on the RAC-REMPEITC Caribe GIS-based database in the WCR can be found at the web site http://cep.unep.org/racrempeitc/maritime-traffic.

2.2.1 Main shipping segments

In this report the traffic within the WCR is sub-divided into and analysed for the following six main traffic segments:

- Tanker
- General cargo
- Tug and supply
- Bulk
- Passenger
- Other

The division in these six segments is made in accordance with the categorization applied in the RAC-REMPEITC Caribe GIS database for maritime traffic in the WCR.

2.3 Analysis of ship traffic data in the WCR

Ship movements registered with both departure and destination ports within the WCR (WCR internal ship traffic) are considered of primary interest with regard to potential future transition to LNG fuel. Ship movements with both or either destination or departure outside the WCR (WCR external ship traffic) are not considered as short sea coastal traffic and thus outside the main focus of this study. Some examples of WCR external traffic are, however, presented for comparative purposes in this analysis.

The REMPEITC database comprises a very large number of registered ship movements on different routes and as this study is aiming at a first rough estimation on the feasibility of LNG as fuel, it is considered accurate enough to carry out indicative analyses and estimations based on a selection of the major routes and ports.

In order to be able to estimate potential future LNG fuel demand, today's total fuel consumption by the total number of registered ship movements within the WCR would provide a relevant reference figure. There are, however, no statistics on the bunker volumes supplied in the WCR ports today and neither any detailed data on the travelled distances nor time spent for each vessel in the registered WCR routes. Therefore it is difficult to do any general estimations of the fuel consumption within the WCR. In chapter 6 some examples are presented for specific segments and routes identified as possible LNG fuelled services to provide some insights in the quantitative calculation of LNG demand.

The figure below represents the total number of ship movement registrations in the period 2007–2008.[2] The total number of registered movements are 207 226 or an average of 108 118 annually.[3] Each movement is registered with one port of departure and one port of destination and for specified ports; the number of ship arrivals and ship departures can be displayed separately. The red circles represent the ports and the size of the circle is proportional to the number of registered arrivals and departures from the port. The seven blue route

[2] The REMPEITC database includes data for 23 months from January 2007 to November 2008.

[3] The estimated annual figures are calculated by multiplying the REMPEITC figures by a factor 12/23.

end markings in the Atlantic Ocean and the one at the mouth of the Panama Canal represent entry/exit points of movements from/to outside the WCR.

It should be noted that the presented ship traffic statistics represent the situation about five years ago and that the present traffic intensity generally is higher than it was in 2007/2008. The increase rate has been somewhat different for different segments and in different regions but as a general average figure, the increase from 2008–2012 may be estimated to about 15% to 20%. The Panama Canal traffic statistics indicate about 17% increase in number of transits during this five year period; see section 3.1.1.

The figures presented in the report are not recalculated to include this 15% to 20% increase and are representing the 2007/2008 situation.

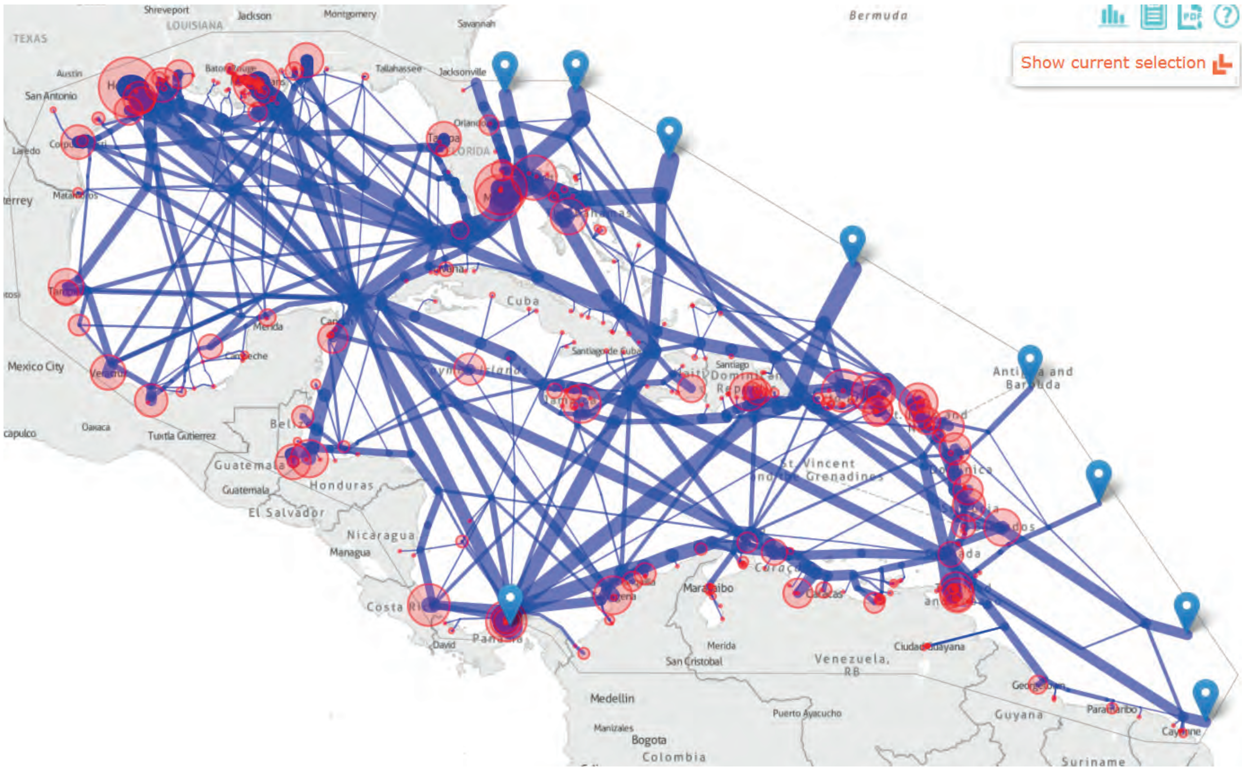

Figure 3*: Overview of the total WCR ship traffic based on more than 200 000 movement registrations in the REMPEITC database*

When all WCR external movements are excluded, still 73% of the movements remain with a number of 78 597 estimated annual WCR internal movements.

These movements are distributed over the six main ship type segments according to the figure below, showing that 43% of the movements are referred to general cargo vessels.

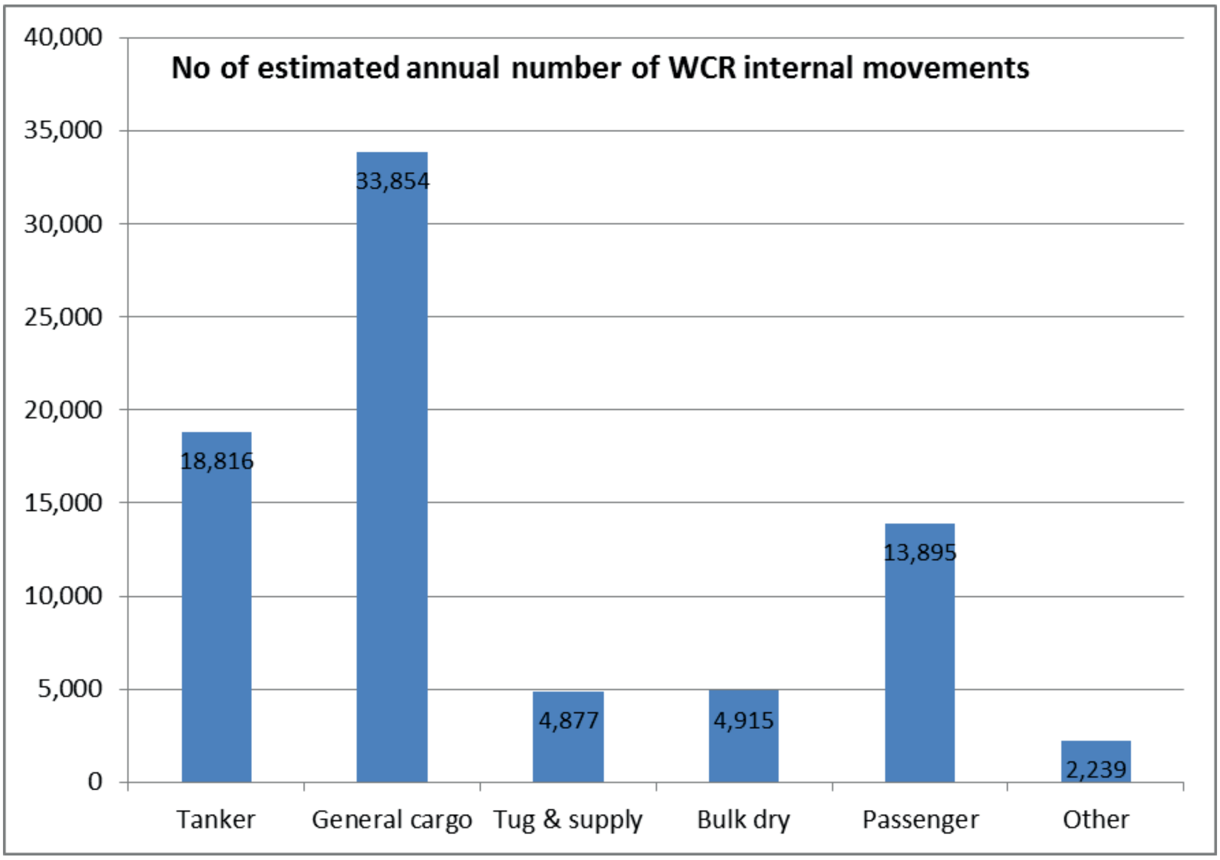

Figure 4: *Estimated annual number of WCR internal movements for the six main ship type segments*

2.3.1 Largest ports

There are about 335 ports in total in the REMPEITC database with registered ship movements. Many of the ports are small and represent only a minor portion of the total number of movements. In order to provide a basis for rough estimations and an overview of the main traffic pattern a ranking of the ports in terms of number of registered movements was derived.

The table below includes the "top-twenty" ports for each of the six main ship type segments. The number of registered movements (registered departures) are presented as estimated annual figures for each port. The table columns also include the sum and the percentage fraction of the total number of registered movements represented by the listed "top-twenty".

Many of the large WCR ports offer bunker supply services for HFO and MGO today but it is not necessarily today's main bunker ports that will be the first to offer LNG bunker supply services in the WCR. None of the WCR ports is ranked among the world top 10 of major bunker ports today.

From the table below it can be noted that typical high frequency ferry ports, i.e. Port of Spain, Trinidad are not listed. This may indicate that some of the regular ferry services between the islands in the WCR are underreported in the utilized statistics.

Table 2 – *Top-twenty ports in 2007–2008: Estimated annual number of movements (excluding external WCR movements) based on registered departure movements*

Rank	Tanker	No of dep.	General cargo	No of dep.	Tug and supply	No of dep.	Bulk	No of dep.	Passenger	No of dep.	Other	No of dep.
1	Houston	2420	Port_Everglades	1915	St._Thomas	563	New_Orleans	532	Port_Everglades	1121	Freeport(BHS)	251
2	Texas_City	894	Miami	1386	San_Juan(PRI)	327	Houston	468	Nassau	1024	Palm_Beach	220
3	Coatzacoalcos	789	Houston	1349	Christiansted	313	Mobile	242	Cozumel	937	Dominica	118
4	Port_Arthur	787	Puerto_Limon	1310	Philipsburg	292	Veracruz	217	Miami	728	San_Juan(PRI)	98
5	Corpus_Christi	687	Puerto_Cortes	1286	Tampa	248	Santa_Marta	152	Freeport(BHS)	672	Port_of_Spain	95
6	Cayo_Arcas_Term.	587	Kingston(JAM)	1173	Marigot	242	Tampa	138	St._Thomas	642	Tampa	86
7	Pointe_a_Pierre	491	Manzanillo(PAN)	1132	Houston	220	Altamira	128	George_Town(CYM)	631	Port_Everglades	85
8	Lake_Charles	484	Cartagena(COL)	1119	Oranjestad	205	Tampico	121	Philipsburg	532	St._Thomas	75
9	Freeport(Texas)	477	Santo_Tomas_de_Castilla	1089	Corpus_Christi	136	Coatzacoalcos	110	St._Lucia	518	Philipsburg	75
10	Hovensa	473	Rio_Haina	1085	St._Kitts	125	Freeport(BHS)	103	Bridgetown	493	Pascagoula	58
11	New_Orleans	437	San_Juan(PRI)	968	Port_Everglades	124	Point_Lisas	101	San_Juan(PRI)	409	St._George's(GRD)	58
12	Puerto_Jose	415	Port_of_Spain	860	Montserrat	86	Corpus_Christi	81	Tortola	380	Jacksonville	51
13	Altamira	378	Veracruz	819	Tortola	84	Rio_Haina	79	Port_Canaveral	371	Pointe_a_Pitre	50
14	Tuxpan	344	Altamira	751	Anguilla	83	Galveston	79	St._John's	351	St._John's	50
15	Port_Everglades	338	Bridgetown	686	Freeport(BHS)	83	Lake_Charles	75	Key_West	336	Bridgetown	40
16	Point_Lisas	299	Puerto_Cabello	645	Port_Arthur	71	Puerto_Cortes	74	Belize_City	278	Houston	36
17	Curaçao	281	Freeport(BHS)	611	St._John's	69	Puerto_Cabello	71	Fort_de_France	277	Guayanilla	33
18	Rio_Haina	247	Cristobal	607	Texas_City	65	Davant	70	Ocho_Rios	249	Cristobal	32
19	Tampa	242	Philipsburg	604	Galveston	65	Brownsville	70	St._George's(GRD)	234	Montserrat	29
20	Tampico	424	Port_au_Prince	572	Guayanilla	60	Port_au_Prince	67	Pointe_a_Pitre	226	Tortola	29
	Sum of listed top-20	11494	Sum of listed top-20	19967	Sum of listed top-20	3461	Sum of listed top-20	2978	Sum of listed top-20	10409	Sum of listed top-20	1569
	61% of the total	18816	60% of the total	33854	71% of the total	4877	61% of the total	4915	75% of the total	13895	70% of the total	2239

2.3.2 Ship size distribution

The ship size of the registered movements in the REMPEITC database is included in terms of deadweight tonnage (dwt) and gross tonnage (GT) and is an important parameter for characterization of the fleet composition and possible LNG fuel demand. A histogram for each segment is presented in the following text and most segments show a peak in the number of movements in the ship size range 5 000–15 000 dwt representing the typical short sea tonnage.

In the REMPEITC map GIS application, the ship size intervals are separated and presented in fixed intervals according to the colour scale in the figure below. The figure shows that the highest number of movements is made by general cargo vessels in the 10–50 000 dwt range and that small cargo vessels and passenger vessels < 10 000 dwt also represent a large share of the total number of the registered movements.

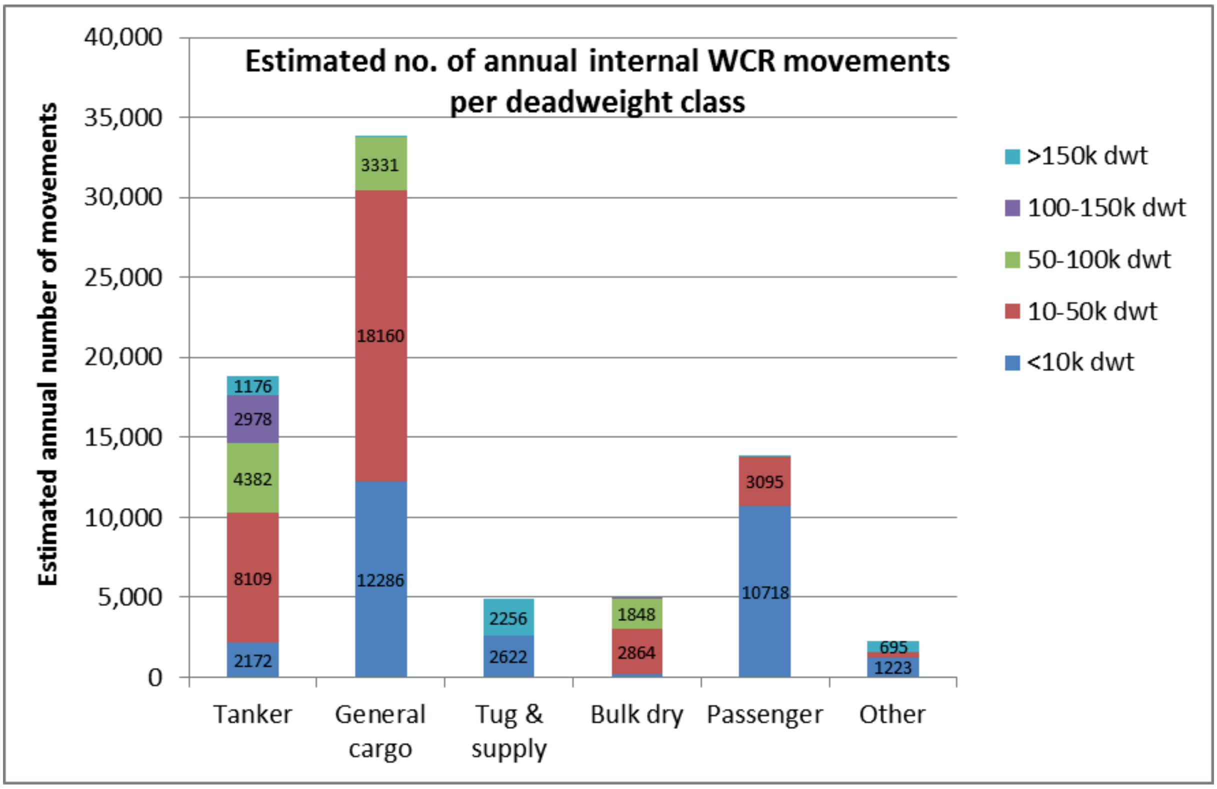

Figure 5: *Estimated number of annual internal WCR movements per ship type segment and dwt class*[4]

2.4 The tanker traffic characteristics

Most types of tankers are operated within the WCR ranging from small product and chemical tankers up to large crude oil tankers. In general tankers are trading all over the WCR. This is also clearly illustrated by the GIS map below showing a number of tanker movements (48 788 per 23 months incl. WCR external) in the area and the overall traffic pattern including oil terminals.[5]

[4] The relative distribution in dwt classes is based on traffic including external WCR. Also note that distribution in dwt classes is less relevant for the tug & supply and passenger segments.

[5] US tanker terminals are not marked in the map.

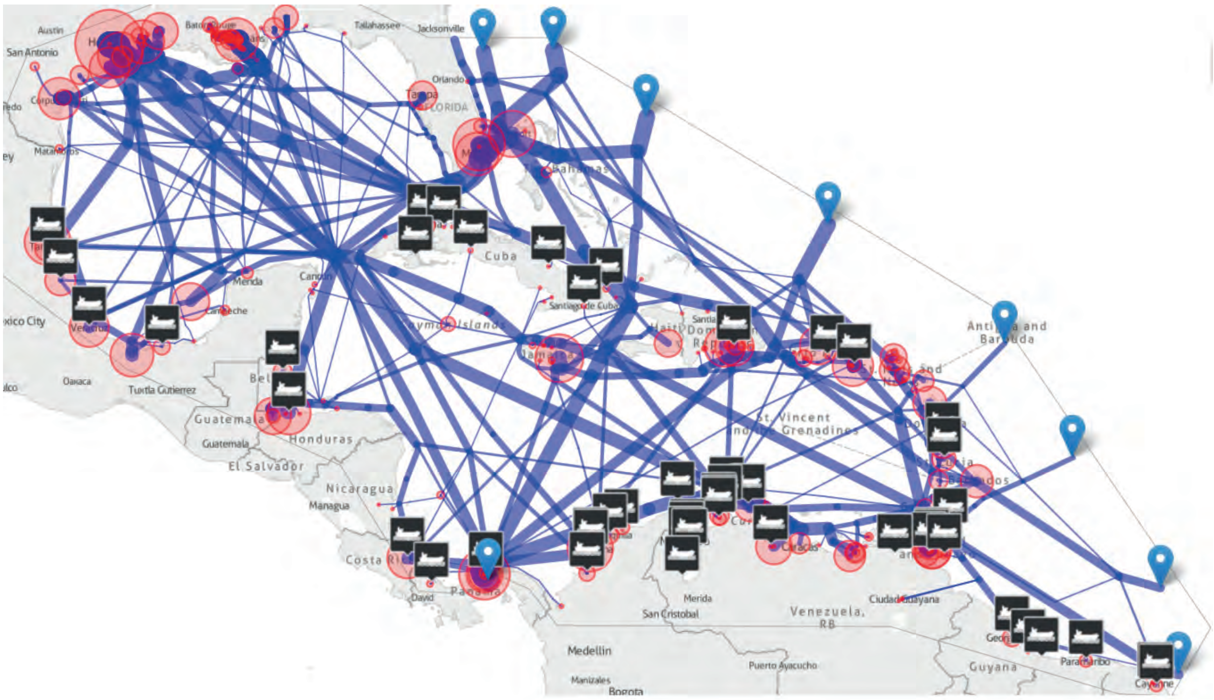

Figure 6: *All tanker movements including WCR external 2007–2008 and tanker terminals*

The figure below with tanker ship size distribution histogram displays peaks in the typical coastal tanker size interval up to 10 000 dwt and 20 000 dwt, but also in the medium range (MR) size 30–50 000 dwt. The peak from 90–120 000 dwt includes Aframax crude carriers and the registrations around 300 000 dwt represent a few rare events with very large crude carriers (VLCC).

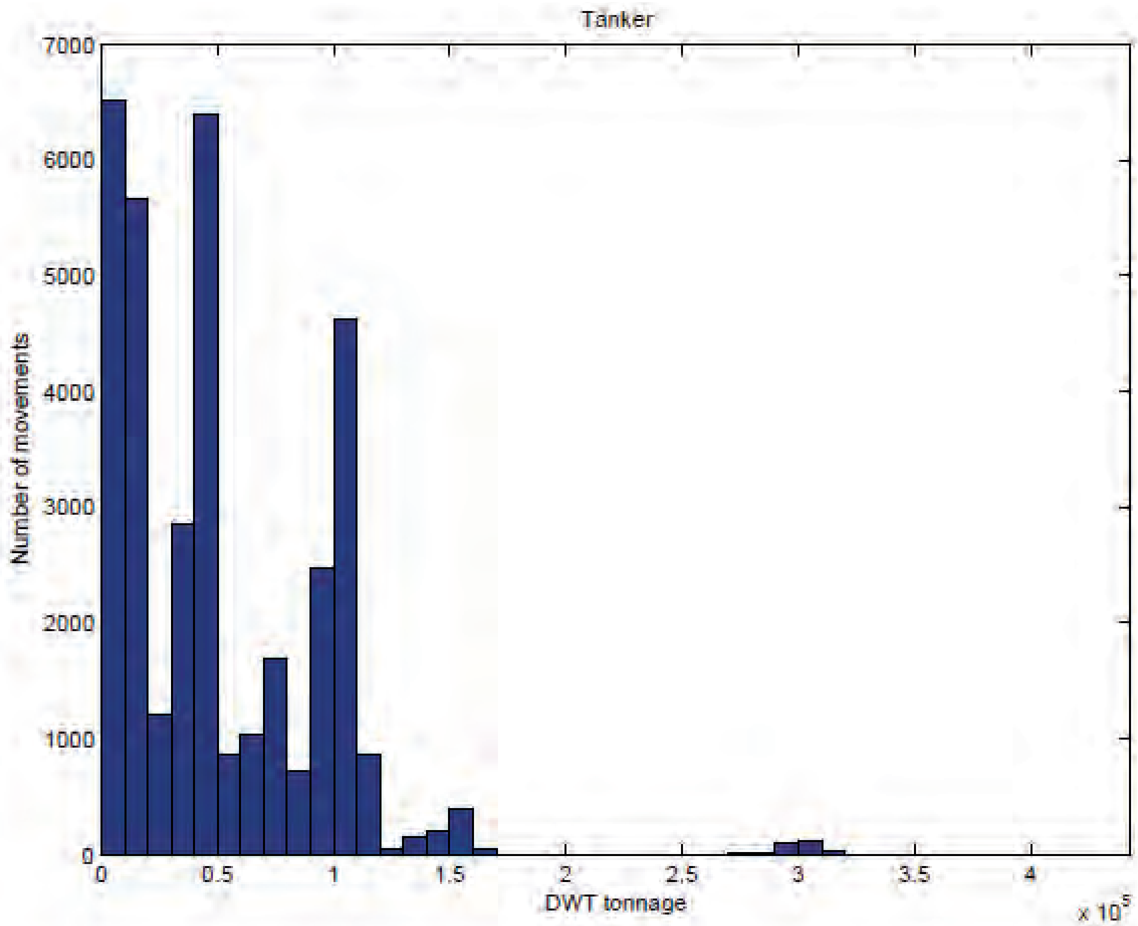

Figure 7: *Size distribution in dwt classes of all internal WCR tanker movements registered from January 2007–November 2008*

Each of the peaks identified in the histogram above corresponds to the specific tanker size segments described below.

2.4.1 Crude oil tankers

In contrast to most crude oil trades in the world, the backbone vessel type of crude oil transportation within the WCR is not the VLCC. Instead most crude trade is done with Aframax tankers. The main reason for this is that few ports within the WCR and particularly in the US are able to accommodate VLCCs.

Figure 8: *Typical Aframax crude oil tanker*

The main route for these Aframax tankers is between a number of large Venezuelan crude export ports and the major US crude import ports along the US Gulf Coast. This trade is clearly visible in the figure below.

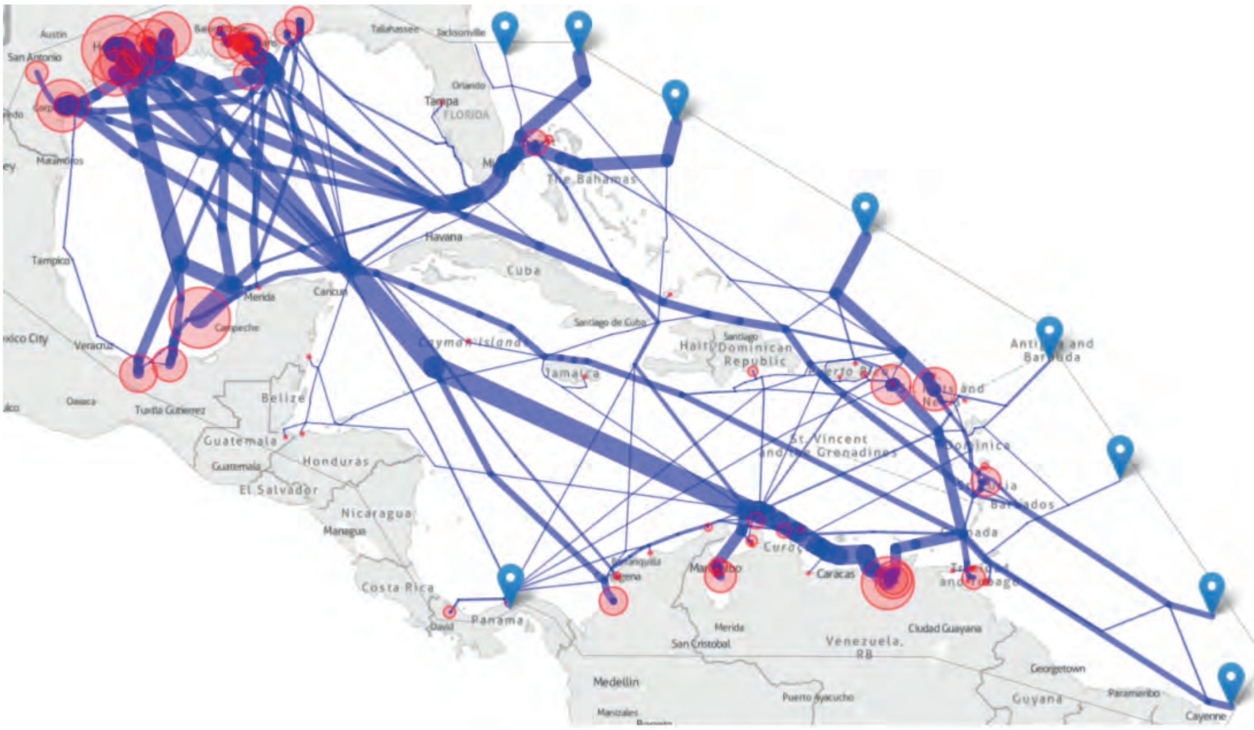

Figure 9: *All tanker movements, January 2007–November 2008 with tankers in the size interval 100–150 000 dwt*

2.4.2 Coastal tankers

Within the WCR coastal tankers are used for regional distribution of energy and other liquid commodities. They trade all over the WCR and are usually not operated on fixed schedules between fixed ports.

Main loading ports for this segment are the large industrial ports with refineries and chemical plants, etc. such as US and Mexican ports along the Mexican Gulf coast as well as ports along the northern coast of South America. The single most visited port areas are the various ports of Trinidad and Tobago.

Figure 10: *Typical coastal tanker (Photograph reproduced courtesy of FKAB Marine Design)*

Areas with high-density traffic are found between the Leeward and Windward islands and in particular between Granada and Trinidad & Tobago in the southern part of the area.

In the figure below ports and movements for tankers up to 10 000 dwt (about 6 900) are displayed.

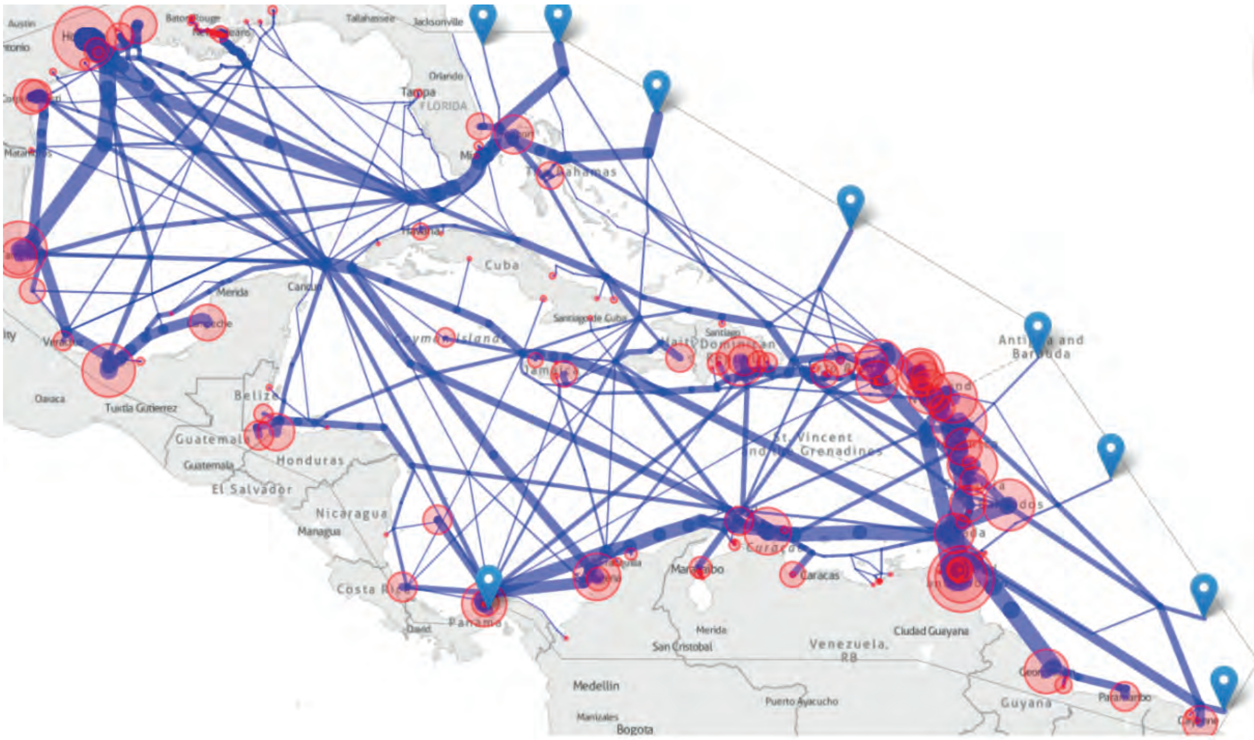

Figure 11: *All tanker movements, January 2007–November 2008 with tankers in the size interval up to 10 000 tonnes*

2.4.3 Medium range tankers

The medium range tankers (MR) operated within the WCR are primarily used for oil products and chemicals. Many MR tanker movements are registered in the US Gulf Coast ports, but their basic trade pattern also include WCR external routes northward along the US east coast. These tankers are seldom operated on WCR internal routes and will not be discussed further.

2.5 General Cargo traffic characteristics

In the REMPEITC database the general cargo segment is divided into the following three sub-segments:

- Container
- Vehicle
- Other general cargo

The figure below, displaying a representative relative distribution from 2008, shows that about half of the segment represents container traffic and the other half is referred to as other general cargo. The sub-category vehicle carrier represents only a minor fraction and is therefore not specifically addressed in the analysis below.

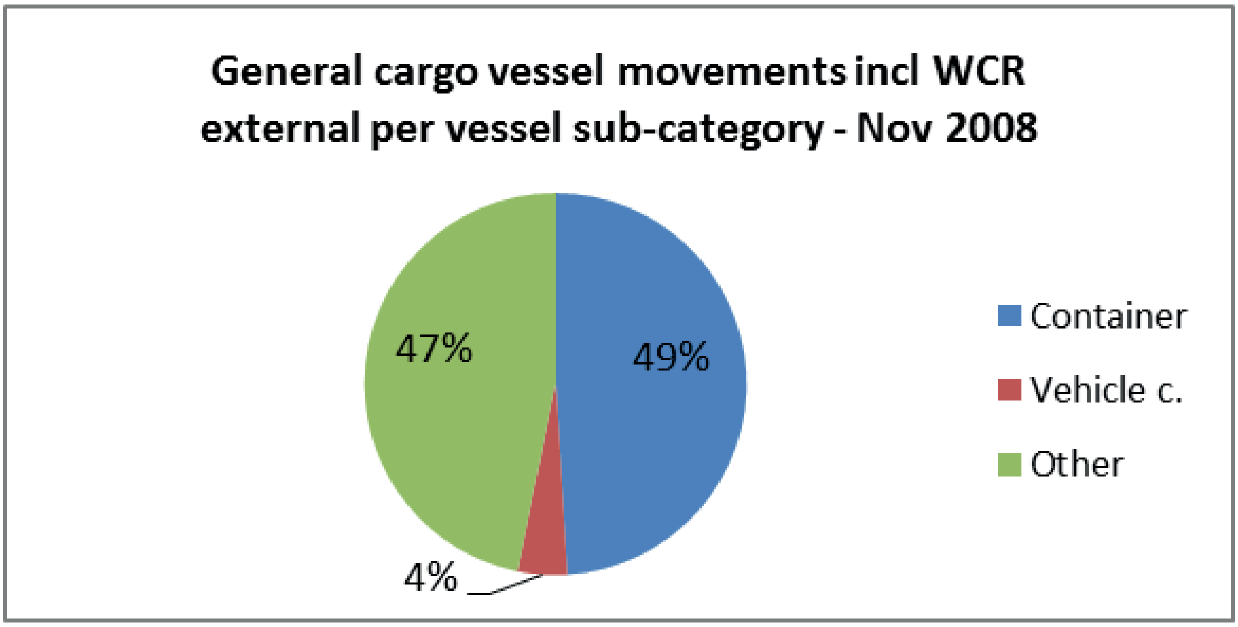

Figure 12: *Relative distribution per vessel sub-category of cargo vessel movements including WCR external, represented by registered data from November 2008*

2.5.1 Container traffic

Container shipping is the fastest growing ship segment within the WCR. The graph in the figure below shows the development between handled tonnes of cargo and handled number of TEUs in a number of WCR countries. Even if the selection of countries is not complete the development is considered representative for the entire WCR.

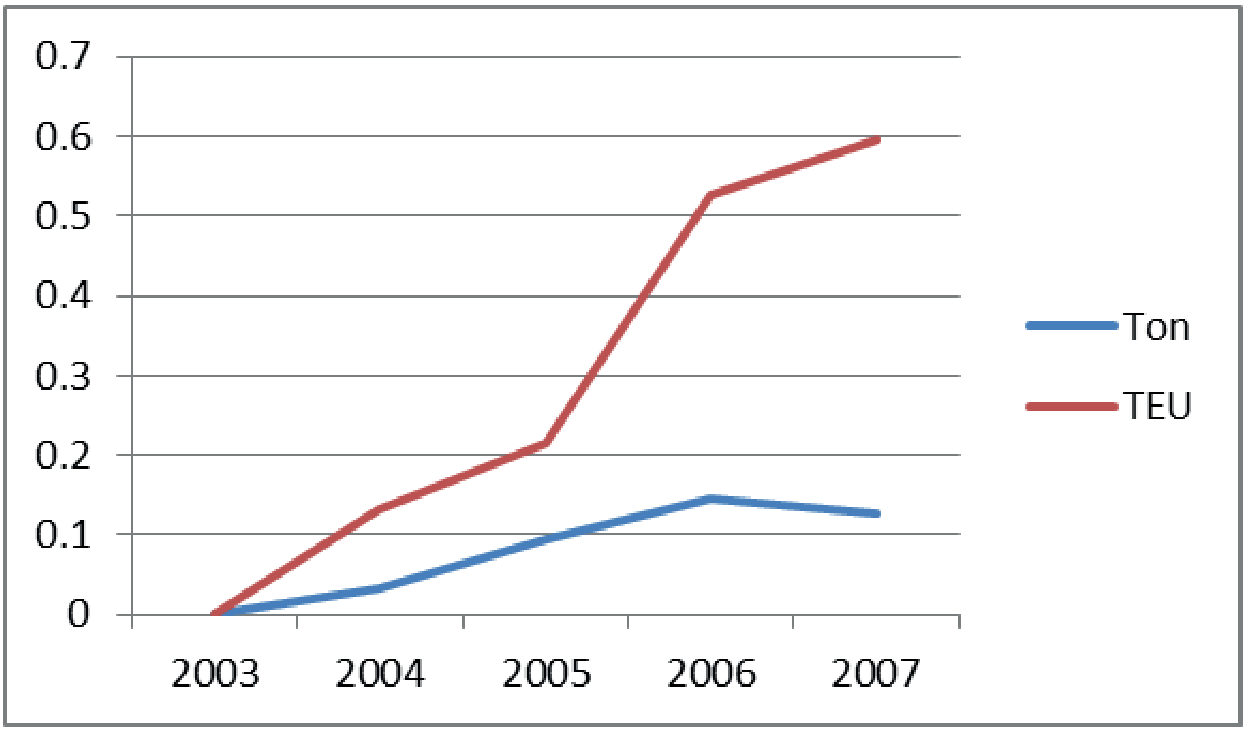

Figure 13: *Growth rate comparison for a selection of WCR countries (Source ECLAC)*

2.5.2 Large container vessels

Larger container vessels with a TEU capacity of above 3 000 corresponding to a GT of approximately 30 000 only transit through the WCR heading to or from the Panama Canal. The main route of these vessels is from the area between Florida and the Bahamas through the Windward passages and down to the entrance of the Panama Canal. If these vessels do stop overs in the WCR, they normally call the main ports in the Bahamas/ Miami region, in Jamaica or in Panama.

The only other main route for these vessels within the WCR is for vessels calling ports in the Houston area entering the WCR via the area between Florida and the Bahamas.

2.5.3 Container feeders

Most WCR internal trades are done with container vessels with a GT of less than 20 000, which correspond to vessels with a TEU capacity of up to approximately 2 000. These vessels called Container feeders are the work-horses of the intra-regional container trades and service most developed ports in the region.

A typical trading pattern for a container feeder is a scheduled route between a number of fixed ports where at least one of them may be considered as a transhipment port connecting the route to the global container flows.

Figure 14: *The 974 TEU container feeder vessel K Breeze (Photograph reproduced courtesy of Crowley)*

The histogram in the figure below displays a peak in the size interval 5–15 000 dwt. This interval accommodates typical container feeder vessels.

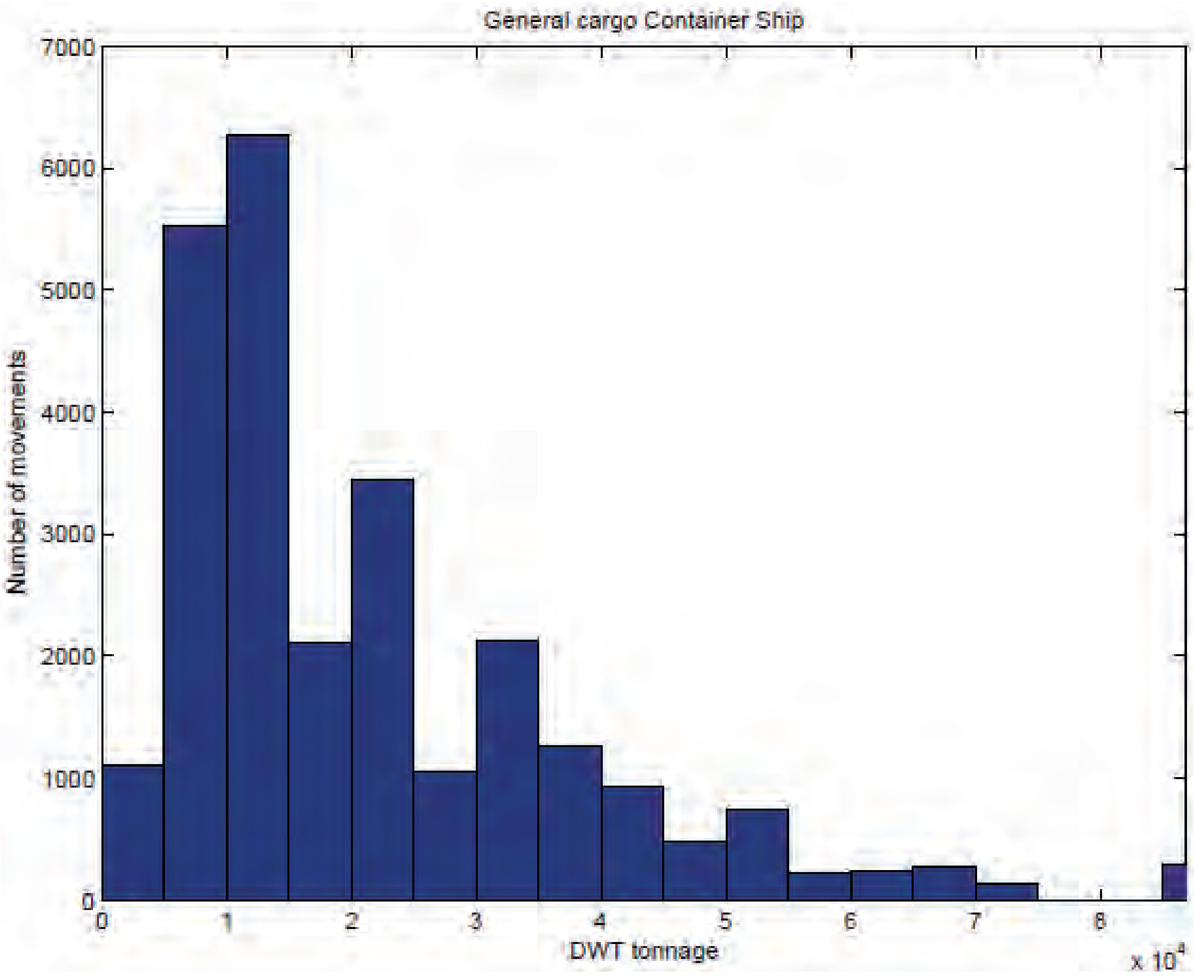

Figure 15: *Size distribution of WCR internal container vessel movements 2007–2008*

Selecting November 2008 as a representative month for the display of registered container vessel traffic in the size interval 0–50 000 dwt, a complex grid incorporating a large number of ports is displayed, shown in the figure below.

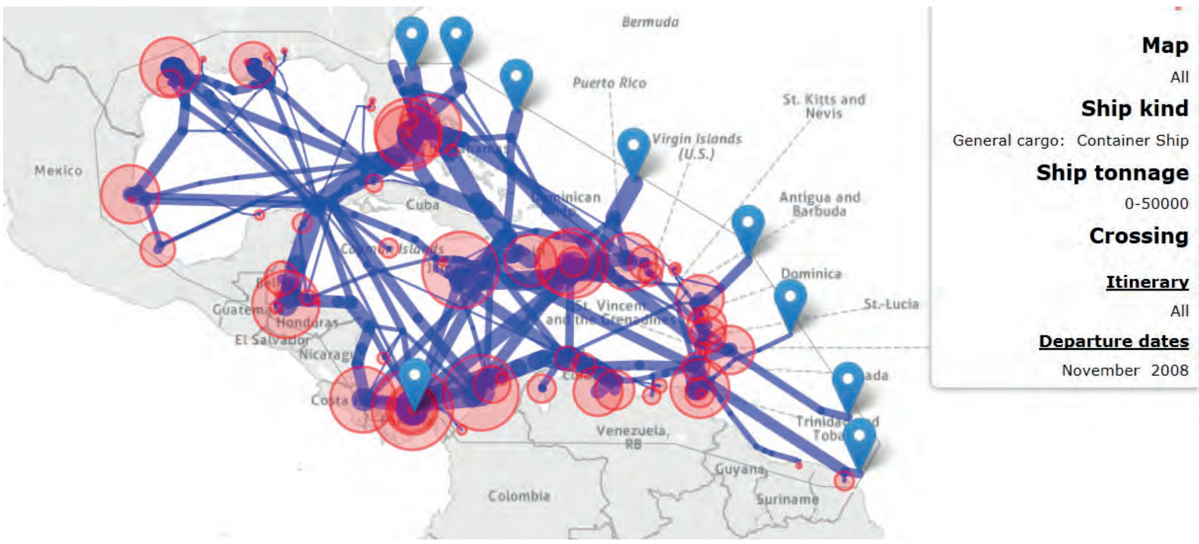

Figure 16: *Trading pattern for General cargo container carriers 0–50 000 dwt*

The figure shows that container feeders are operated all over the WCR visiting most developed ports in the area.

2.5.4 Other general cargo

By tradition small general cargo carriers have been a very important part of the sea based transportation system within the WCR. Their onboard cargo handling equipment, cranes, etc. allow them to call less developed ports all over the area. Yet flexible and cheap the cargo handling efficiency is low compared to modern container feeders but since they require significantly less port investments, they still have their markets in the WCR.

From the map in figure 18 it is clear that these vessels are operated all over the WCR.

Figure 17: *Typical small geared general cargo carrier calling Pointe-a-Pitre on Guadeloupe (Photograph reproduced courtesy of Urs Steiner)*

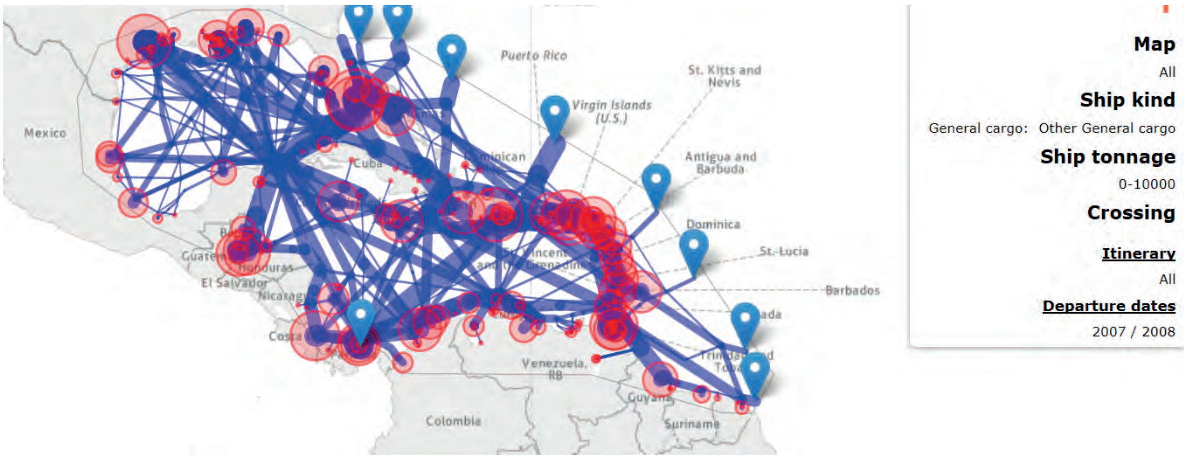

Figure 18: *Trading pattern for General cargo carriers below 10 000 dwt*

As displayed in the histogram below these vessels are usually small with the main sizes below 10 000 dwt.

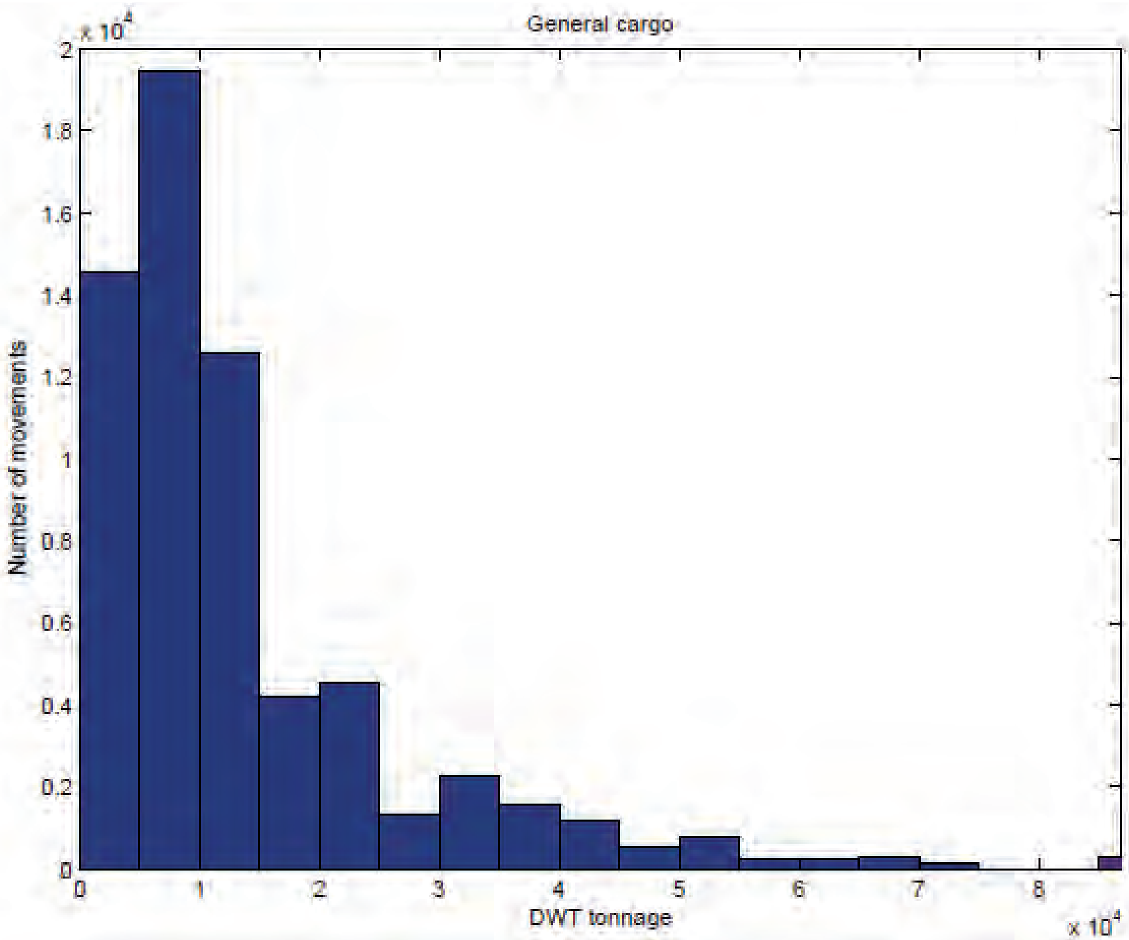

Figure 19: *Size distribution of WCR internal cargo vessel movements 2007–2008*

2.6 Tug and supply vessel traffic characteristics

For the segment of tug and supply vessels a total of 9 640 movements are registered (over the total 23-month period of the REMPEITC database).

The geographical distribution indicates that there is a concentration of tug and supply vessel traffic in two areas – in the US Gulf Coast area and around the Virgin Islands – which can be seen in the figure below.

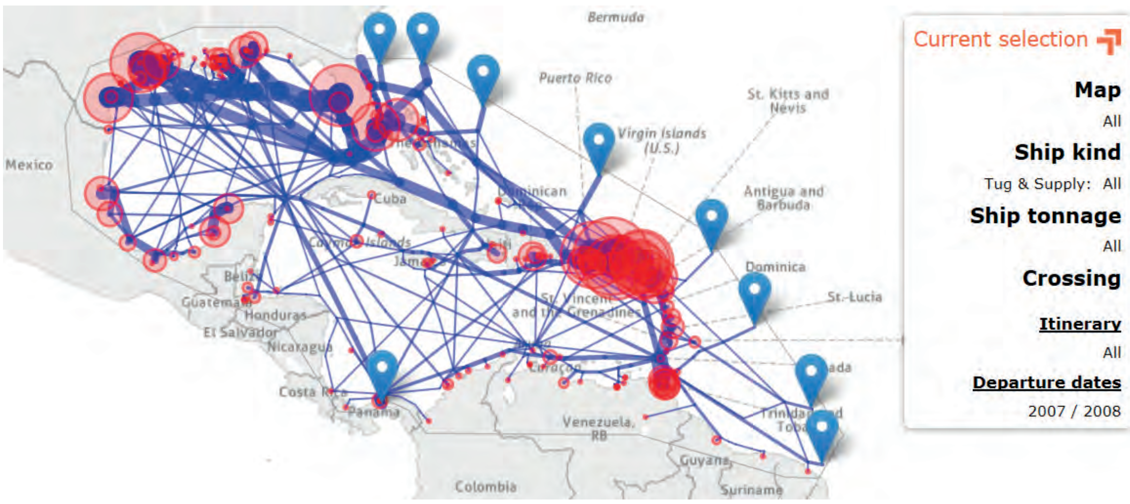

Figure 20: *Tug and supply vessel traffic in the WCR*

2.6.1 Harbour tugs

Three dominant sub segments are included in the tug and supply segment. For tugs there are two main applications within the WCR. The first one, commonly used in all ports within the WCR, is the harbour tug assisting vessels entering or leaving ports.

Figure 21: *Typical harbour tug*

2.6.2 ITB/ATB

The second main tug application is ITB/ATB/push barge solution where both normal tugs and tailor made tugs are used for moving one or several barges with all kinds of commodities between ports. There are two high-density areas for this kind of operation.

The first one is along the US coast where a lot of these combined units are operated. The other area is around the northern Leeward Island where these units distribute all kind of commodities including water, energy and general cargo, etc. between the different islands.

Figure 22: *An oil ATB outside Key West (Photograph reproduced courtesy of Crowley)*

2.6.3 Platform supply vessels

Supply vessels of all kinds are commonly used for the offshore oil and gas industry along the US Gulf Coast operated out of different base ports primarily in the Houston area. The figure below shows this traffic but also includes all traffic with tugs/ATBs and ITBs in the area.

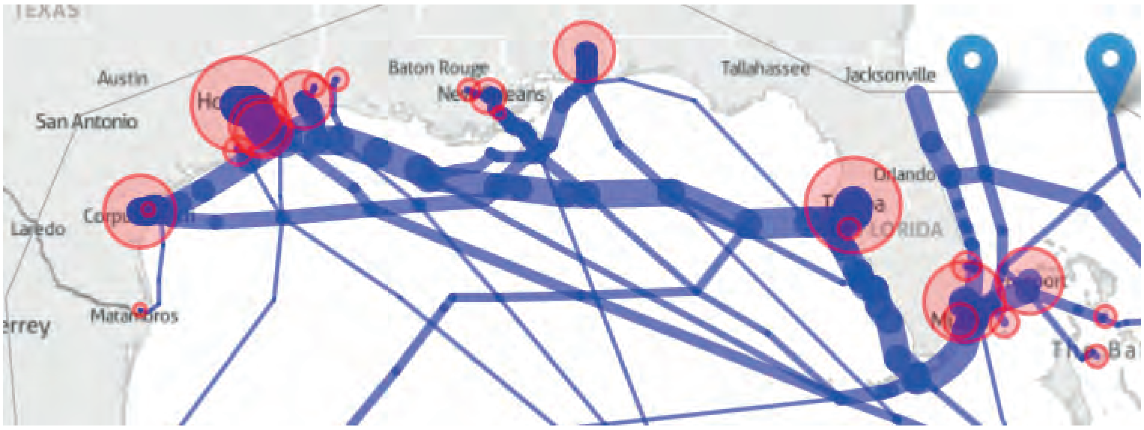

Figure 23: *Tug and supply vessel traffic in the US Gulf area represented by April 2008*

Since 2008 when the main data used for this report was retrieved the activities of platform supply vessels (PSVs) in the waters along the north coast of South America have increased significantly due to the increased interest in the exploration of the offshore oil and gas resources in that area.

2.7 Dry bulk shipping characteristics

The dry bulk segment within the WCR consists of two typical segments. The main segment is dry bulk shipping related to import and export of typical dry bulk commodities such as coal, grain, ore, etc. from the US Gulf Coast ports (USACE NDC 2012). Most of this shipping is on behalf of ports outside the WCR. The main trading routes for this segment is from the US Gulf Coast ports to the inlet of the Panama Canal or south of Florida and then towards the North American east coast or Europe. Therefore it will not be further evaluated in this study.

The other type of dry bulk shipping is a more small-scale artisanal intra-regional dry bulk shipping, which is very similar to the small general cargo segment and therefore difficult to distinguish. In terms of trading patterns and other characteristics it looks relatively similar to the general cargo segment.

2.7.1 Size distribution

The size distribution for registered WCR internal movements with dry bulk carriers is presented in the figure below.

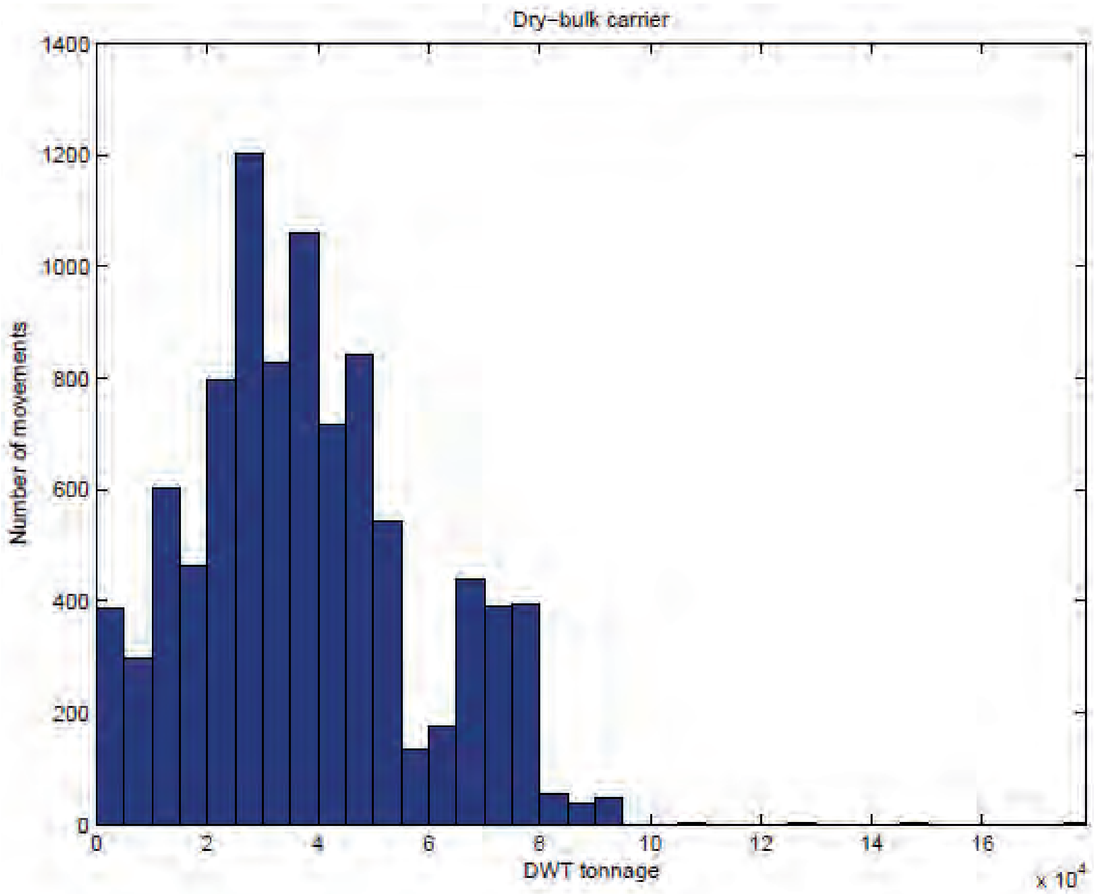

Figure 24: *The size distribution for registered WCR internal movements with dry bulk carriers*

2.8 Passenger vessel traffic characteristics

In principle, there are two types of passenger traffic within the WCR, regular passenger traffic and cruise.

Regular passenger traffic between the Caribbean Islands and elsewhere in the WCR is basically conducted by vessels ranging from 100 up to 10 000 GT. Passenger vessels ranging from 10 000–150 000 GT are assumed to represent cruise ships.

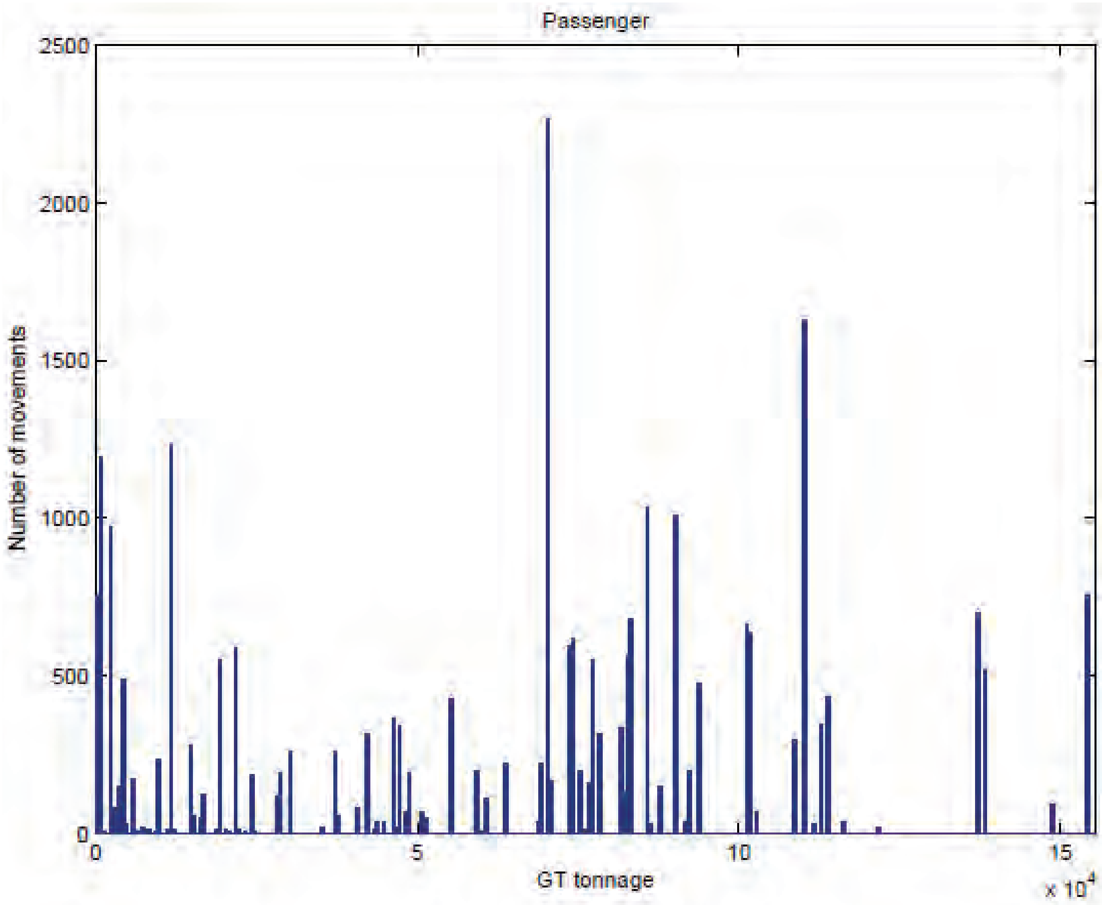

Figure 25: *The size distribution for registered WCR internal movements of passenger vessels*

2.8.1 Regular passenger vessels

There are a large variety of passenger vessels in the area ranging from small ferries operated in short distances between small and sheltered island communities up to large vessels operated between the main islands in the Caribbean and elsewhere. There are also high speed craft (HSC) ferry services operated in many places of the WCR.

The REMPEITC map below clearly displays that the main area for this traffic is between the different Caribbean islands. Note that the ferry traffic between islands Trinidad and Tobago is not reflected in the map.

Figure 26: *Trading patterns in the WCR of passenger vessels below 10 000 GT*

2.8.2 Cruise

The cruising industry within the WCR is huge and most of the services are operated from the main cruise ports in southern Florida. As displayed in the figure below, most of these vessels are trading the Bahamas, the Caribbean Islands as well as the waters of Mexico, Belize, Guatemala and Honduras. The cruising activities are operated year round with a peak season between October and March. A typical cruise trip runs for seven days.

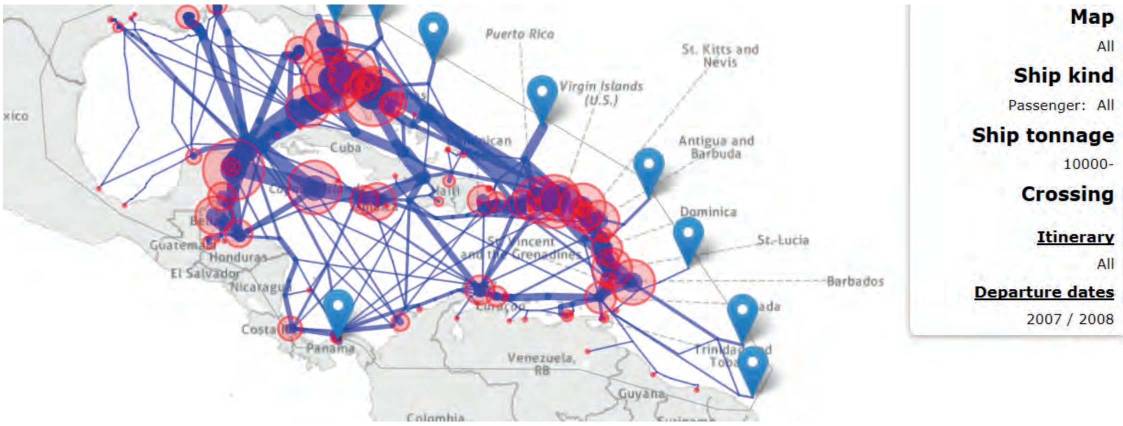

Figure 27: *Trading pattern for passenger vessels above 10 000 GT within the WCR*

Figure 28: *RCCL* ***MONARCH OF THE SEAS*** *on a cruise within the WCR*

2.9 Other ship traffic

The other vessel group is a relatively small segment with various types of vessels not typically characterized as short sea shipping. One group that, however, may be of future interest for LNG fuel adaptation is the fishing vessels.

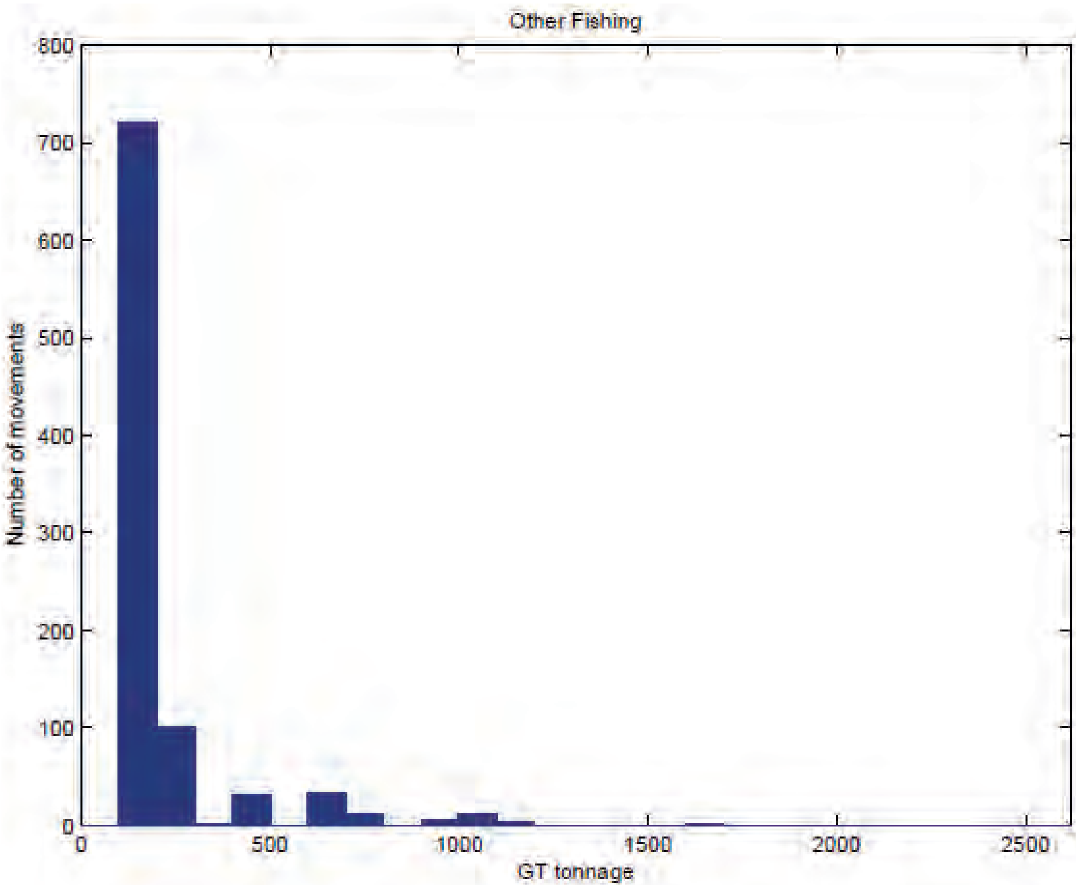

Figure 29: *Size distribution histogram of fishing vessels*

There are about 1 000 fishing vessel 100–10 000 GT movements registered with a concentration in the Lesser Antilles islands (Leeward Islands) and with Trinidad and Dominica as the largest ports.

As seen in the figure below, 90% or about 900 are in the size range 100–500 GT.

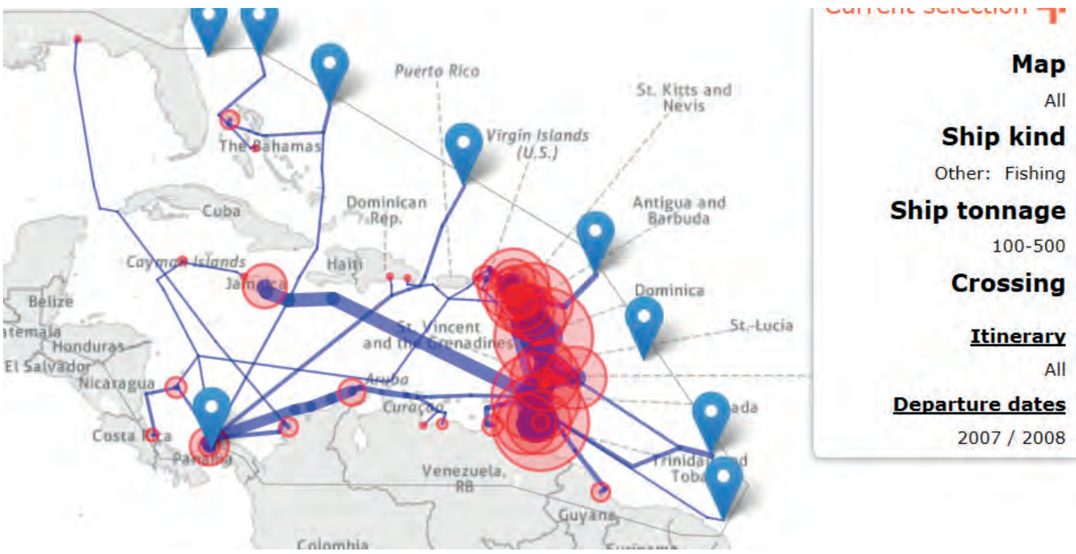

Figure 30: *Trading pattern with fishing vessels in the size range 100–500 GT*

2.10 External traffic – Ships entering and departing the WCR

2.10.1 Panama Canal related traffic

For the WCR external traffic passing through the Panama Canal, there are detailed statistics available from Panama Canal Authority. The graph in the figure below shows the development over the past 10 years indicating a significant increase in the dry bulk segment compared to the years 2007 and 2008 used as references for the RAC-REMPEITC comparisons.

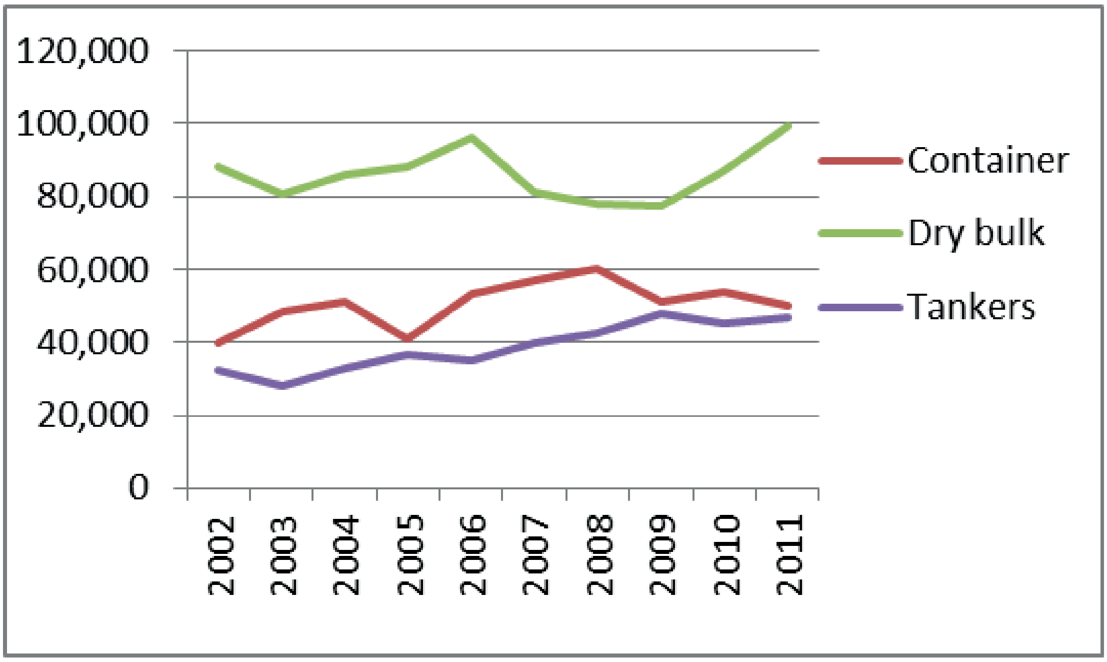

Figure 31: *Segment divided transhipments in long tons (Panama Canal Authority)*

The three segments containers, dry bulk and tankers dominate the transhipment through the Panama Canal. The division between ship types in 2011 is displayed in the figure below, showing that the three major segments represent 68% of the number of ship passages.

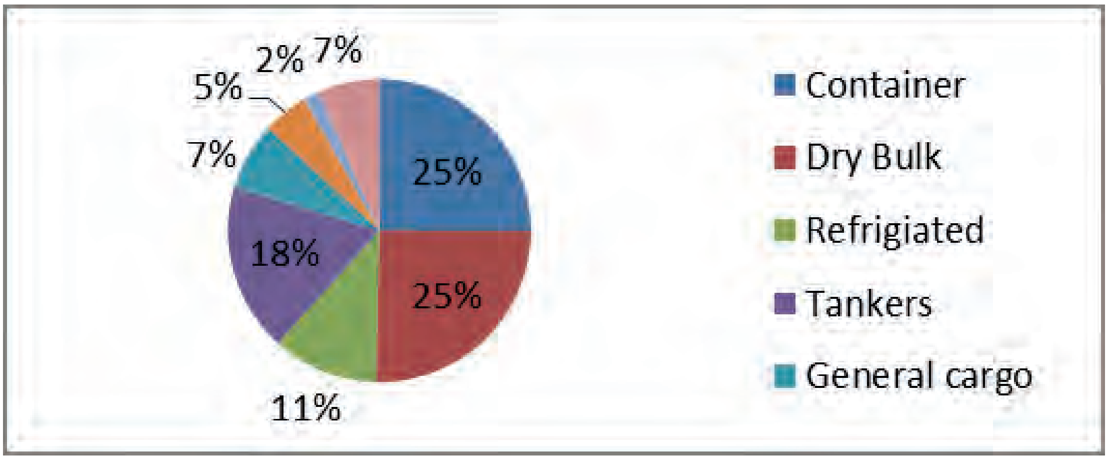

Figure 32: *Distribution of Transits between ship types 2011 (Panama Canal Authorities 2012)*

If the comparison is presented in terms of cargo quantities the three major segments represent 90% of the total transported cargo weight.

In order to display the pattern of departures and destinations within and outside the WCR, all registered movements (January 2007–November 2008) are shown in the figure below. A total of 24 301 (12 679 annual) ship movements, all segments, were registered in the Panama Canal. This figure corresponds to 12% of all the ship movements registered in the REMPEITC database.

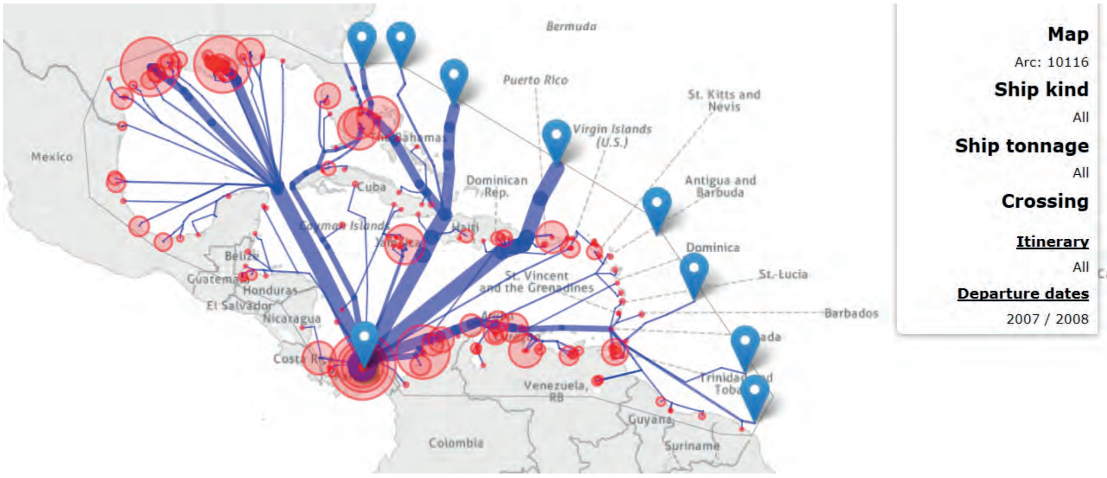

Figure 33: *All ship types passing through the Panama Canal (Arc 10116) January 2007–November 2008*

Except for Manzanillo in Panama, Houston (1 327 movements) and New Orleans (1 176 movements) are the main WCR ports for the Panama Canal traffic (see figure above). Of the total 24 301 passages (12 679 annual) through the canal 9 491 (4 952 annual), or 39% of the traffic is bound for or arriving from the Atlantic Ocean without calling at any WCR ports.

2.10.2 The Atlantic Ocean – WCR arrivals from and departures to the Atlantic

Registered in routes entering from or exiting to the Atlantic Ocean were 55 379 ship movements from all segments. This figure corresponds to 12% of all the ship movements registered in the REMPEITC database. The one most frequently used (marked with green in the below figure) shows 12 589 registrations with Houston (1 632 movements [of which 760 by tankers]) as the main port within the WCR.

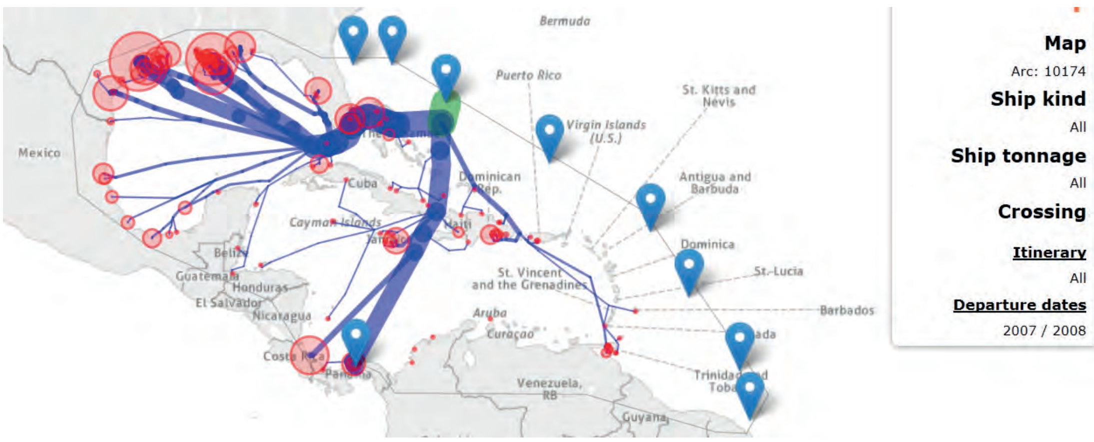

Figure 34: *WCR arrivals from and departures to the Atlantic*

3
Key trends and future scenarios

3.1 General key trends

3.1.1 Panama Canal expansion

Since the opening of the Panama Canal in 1914 it has been a major global shipping route and for years the limitations set by the locks in the canal was decisive for how ships in various segments were designed. During the late twentieth century this changed and a significantly larger share of the newly built ships were designed without considering the Panama Canal limitations. This development has reduced the relative importance of the canal in a global perspective.

In 2006 it was decided to expand the canal. The main reason was to secure its position as one of the major global shipping routes for the future as well as regain some lost market shares. Some segments are more influenced than others by this development. The on-going expansion is due to be completed by 2014 and will allow more and larger ships to pass.

The general cargo segment, and especially the container shipping, is probably the segment that will be most affected by the expansion plans. Vessels that are too large to pass the present canal do most of the intercontinental container trades today. The new dimensions will once again make it possible for the large intercontinental container flows to pass through the Panama Canal and the most plausible development is that the growth in TEU or tonnes shipped through the canal will grow faster than the global shipping growth.

For other main segments such as dry bulk and tankers the result of the new canal size is more ambiguous and a plausible development is that the flows tonne wise will increase in line with the global shipping growth but that the number of passages will be less, as vessels passing the canal will grow in size.

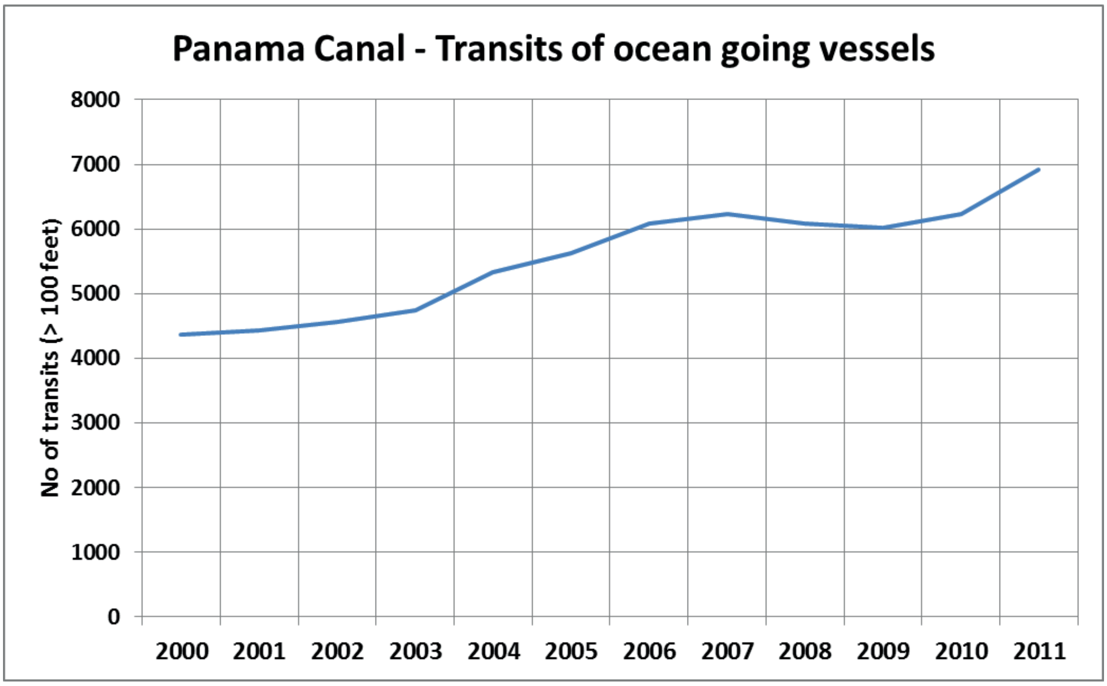

Figure 35: *Development of Panama Canal transits (Panama Canal Authority)*

In a long-term perspective with continued increasing maritime traffic and if the capacity of the expanded Panama Canal will become insufficient, the feasibility of another canal project may be subject for renewed considerations.

3.1.2 Environmental requirements

Shipping as such has been a business with rather limited environmental requirements of either commercial or regulatory character. During the last decade this situation has changed drastically. Today shipping is under heavy pressure from authorities, clients and the general public to improve the environmental performance of shipping both in a local, regional and global perspective.

This development is forcing the shipping community to invest in new vessels and technologies, change to alternative fuel, develop the general operational performance as well as increase the level of education of the professionals involved in shipping. This development has a significant influence also on shipping in the WCR.

Recent designations of the North American ECA and the US Caribbean ECA within the WCR will further enhance the development of the environmental performance of the fleet operating in the WCR.

3.2 Additional segment related key trends

3.2.1 Tankers

The tanker shipping within the WCR is relatively stable and it will probably develop without any dramatic short-term changes. Some minor trends may, however, be identified and mentioned.

The increasing interest in using LNG as the main source of energy in some of the island communities in the WCR will likely contribute to an increasing demand for and construction of small- and medium-size LNG carriers.

In recent years some of the main refineries in the WCR have been closed because of poor profitability. A typical example is the Hovensa refinery at the island of St Croix, US Virgin Islands. Such development will have significant local impact on the tanker shipping segment but seen in a regional perspective the impact is considered limited.

3.2.2 General Cargo

A very clear trend in the WCR is that local and regional small-scale shipping operation is outrivalled by ship operations more integrated with the passing large-scale shipping operation. This is also connected to port development and efficiency.

Segments that are most affected by this development is the General Cargo segment where cargo is moving from small general cargo into containers, which then is handled in the growing container flows (Sánchez and Wilmsmeier, 2009). For the WCR communities this implies reduced shipping costs also for internal WCR cargo transportation as long as the ports are connected to the container infrastructure systems either by feeder or a transhipment port.

The losers of this development are everybody involved in the traditional artisanal shipping systems that used to be the backbone of the WCR internal distribution such as:

- Small and less developed ports
- Societies and private companies relying on these ports
- Owners and operators of small general cargo and bulk carriers

From the society's point of view, it is of great importance to be included in container feeder networks. In order to keep up competitiveness it may be necessary to invest and develop key ports to become attractive for the cargo owners and shipping companies to use.

As identified in the previous section, the expansion of the Panama Canal will have a significant impact on the general cargo segment and a plausible development is that the number of large container carriers passing through the WCR will grow.

As described in the previous section the number of large transhipment ports for containers is limited especially in the central part of the WCR. Several of the large regional ports in the area, such as the Kingston Container Terminal of Jamaica, are investing heavily to be able to attract the global large-scale container routes to include stop over in the WCR on its way to or from the Panama Canal. If one or several of these ports are successful, it may create new trading patterns for container feeders, reducing the demand for small general cargo even more.

3.2.3 Dry bulk

The main dry bulk segments are considered relatively stable but influenced by the general trends identified in section 3.1. For the smaller segment there is a similar trend as for the general cargo segment described in section 3.2.2. Based on the high efficiency that usually characterizes the container flow, some of the typical bulk commodities may be containerized leading to a reduced demand for small bulk vessels.

3.2.4 Supply and tug

For the tug segment, it is difficult to identify any clear trends except the general trends stated in section 3.1. Concerning the supply segments there is a possibility for a significant increase in the supply vessel operations along the northern coast of South America since there are several unexploited offshore oil and gas reserves in that area.

3.2.5 Passenger

The passenger segment differs from route to route and it is difficult to identify any general trends concerning the future development of the passenger within the WCR. It should, however, be noted that passenger traffic and in particular the cruising segment often is influenced by external requirements for improved environmental performance and public perception, and that environmental performance may gain increasing importance as a competitive market factor.

3.2.6 Other ship types

Other ship types cover a wide scope of vessel types operating in different areas and no clear-cut general development trend has been identified for this segment within the WCR.

3.3 Baseline scenario with regard to emission control

It is well known that the shipping industry represents a significant contribution to global airborne pollution and that the three worldwide-established MARPOL Annex VI-designated ECAs are effective measures for improvement of air quality and reduction of health risks. The measures taken to reduce current ship emission levels to the ECA standard are a most cost-effective way to achieve air quality improvement in the area. In the proposal to IMO for the US Caribbean ECA, US EPA estimated emission reductions of 10 000 tonnes of NO_x, 3 000 tonnes of particles PM2.5, and 28 000 tonnes of SO_x (US EPA 2011).

The ECAs in the Baltic Sea area, the North Sea area and the recent North American ECA that came into effect 1 August 2012, all cover sea areas with dense sea traffic and environmentally sensitive surrounding coastal zones and islands. The US Caribbean ECA that will come into effect in 2014 also represents sensitive sea and coastal areas located in an area of the WCR with dense ship traffic and a wide range of ship types. The ECA designation will influence the operational costs of shipping in the area but the cost increase is expected to have marginal impact for end consumers. US EPA has estimated that a five-day cruise from the US mainland to Puerto Rico will increase less than 1% and the cost increase for transportation per TEU container will also stay below 1% (US EPA 2011). Other stakeholders claim that costs will be more significantly influenced.

For ship operations within NO_x ECAs, ships constructed from 2011 must comply with the "Tier II" standard for marine diesel engines of Reg. 13 of MARPOL Annex VI. Ships constructed from 2016 will be required to comply with the more stringent Tier III NO_x emission standard.

3.3.1 North American ECA

The North American ECA extends to about 200 nautical miles off the coast except in the narrow areas between Florida, Cuba and Bahamas.

For the internal WCR registered movements, 28% of all ship movements were movements in the ports within the North American ECA.

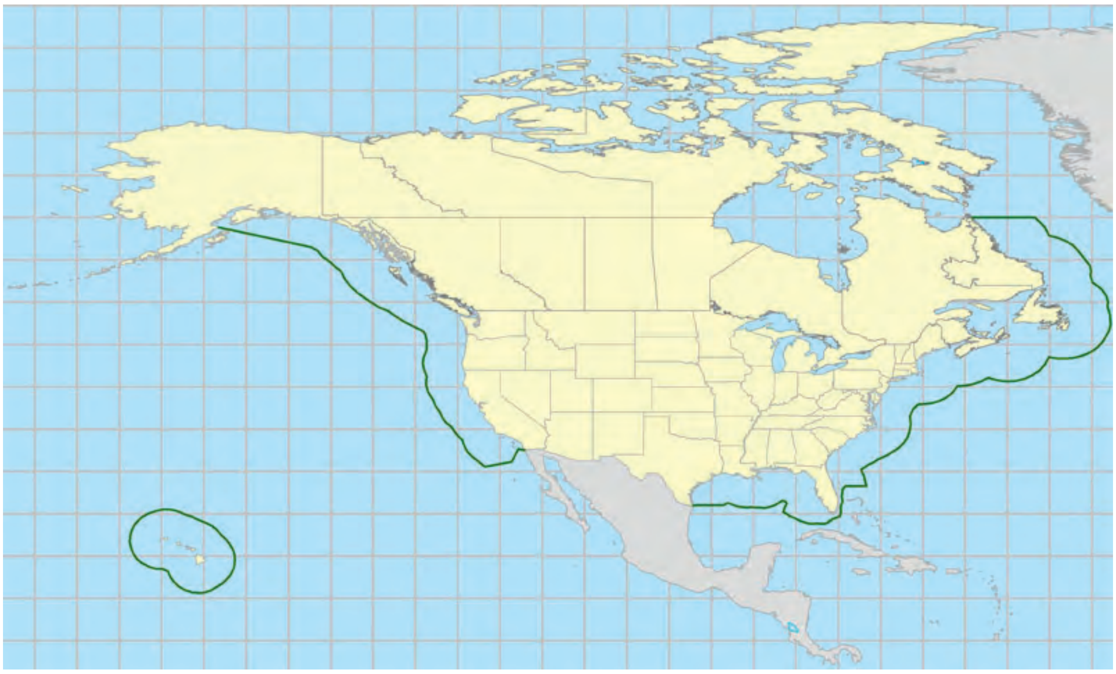

Figure 36: *North American ECA (US EPA 2010)*

3.3.2 US Caribbean ECA

For the internal WCR registered movements, 9% of all ship movements in the REMPEITC database (counted by departure movements) are referred to ports within the US Caribbean ECA.

The US Caribbean ECA will basically affect ships calling at San Juan and other ports in Puerto Rico and St Thomas, Hovensa and Tortola in the US Virgin Islands. The Mona strait between Hispaniola and Puerto Rico is about 70 nautical miles wide and has a dense traffic including Panama Canal – Atlantic Ocean transits. The ECA stretches only about 15 nautical miles in the Mona strait, about 40 miles off the north coast of Puerto Rico and 50 miles off the south coast.

Figure 37: *The US Caribbean ECA (BP Marine 2012)*

3.3.3 WCR ports outside the ECAs

For the internal WCR registered movements, 63% of all ship movements in the REMPEITC database (counted by departure movements) are referred to WCR ports located outside the designated ECAs. Assuming that only ships calling ports within the two presently designated ECAs will operate with sulphur emissions in compliance with the ECA requirements indicates that a majority of the WCR internal ship movements still will be with vessels without any measures taken for reduction of SO_x emissions.

The figure below indicates that the introduction of the North American ECA (NA ECA) will have a significant impact on the tanker segment in which 44% of the ship movements have to be carried out by ships compliant to the NA ECA requirements but only another 3% more need to adapt when the US Caribbean ECA comes into force. For the general cargo segment a major part or 71% of the internal WCR ship movements will still be calls to ports outside the designated ECAs.

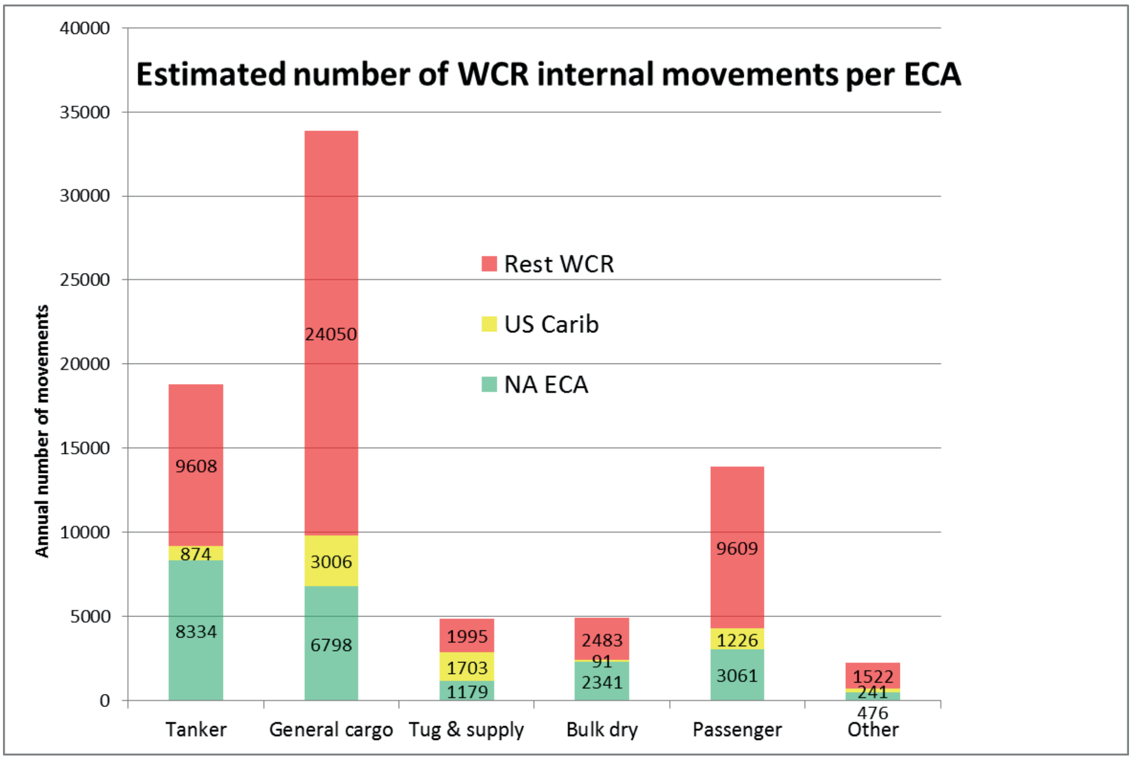

Figure 38: *Estimated annual number of WCR internal movements calling at ports within and outside ECAs*

It should, however, also be noted that if a ship has been designed or retrofitted for operation with LNG fuel in order to comply with ECA regulations, it is likely that LNG, because of lower price and operational cost, may be found to be a preferable fuel also for operation outside the ECAs.

In the table below with the top-twenty list of ports for internal WCR calls in the period from January 2007 to November 2008, ports within the North American ECA and the US Caribbean ECA respectively have been marked with different colour shadings to illustrate where the designated ECAs will have an impact.

Table 3 – *Top-twenty ports in 2007–2008: Estimated annual number of internal WCR movements. Ports within North American ECA green background and for the US Caribbean ECA yellow*

Rank	Tanker	No of dep.	General cargo	No of dep.	Tug and supply	No of dep.	Bulk	No of dep.	Passenger	No of dep.	Other	No of dep.
1	Houston	2420	Port_Everglades	1915	St._Thomas	563	New_Orleans	532	Port_Everglades	1121	Freeport(BHS)	251
2	Texas_City	894	Miami	1386	San_Juan(PRI)	327	Houston	468	Nassau	1024	Palm_Beach	220
3	Coatzacoalcos	789	Houston	1349	Christiansted	313	Mobile	242	Cozumel	937	Dominica	118
4	Port_Arthur	787	Puerto_Limon	1310	Philipsburg	292	Veracruz	217	Miami	728	San_Juan(PRI)	98
5	Corpus_Christi	687	Puerto_Cortes	1286	Tampa	248	Santa_Marta	152	Freeport(BHS)	672	Port_of_Spain	95
6	Cayo_Arcas_Term.	587	Kingston(JAM)	1173	Marigot	242	Tampa	138	St._Thomas	642	Tampa	86
7	Pointe_a_Pierre	491	Manzanillo(PAN)	1132	Houston	220	Altamira	128	George_Town(CYM)	631	Port_Everglades	85
8	Lake_Charles	484	Cartagena(COL)	1119	Oranjestad	205	Tampico	121	Philipsburg	532	St._Thomas	75
9	Freeport(Texas)	477	Santo_Tomas_de_Castilla	1089	Corpus_Christi	136	Coatzacoalcos	110	St._Lucia	518	Philipsburg	75
10	Hovensa	473	Rio_Haina	1085	St._Kitts	125	Freeport(BHS)	103	Bridgetown	493	Pascagoula	58
11	New_Orleans	437	San_Juan(PRI)	968	Port_Everglades	124	Point_Lisas	101	San_Juan(PRI)	409	St._George's(GRD)	58
12	Puerto_Jose	415	Port_of_Spain	860	Montserrat	86	Corpus_Christi	81	Tortola	380	Jacksonville	51
13	Altamira	378	Veracruz	819	Tortola	84	Rio_Haina	79	Port_Canaveral	371	Pointe_a_Pitre	50
14	Tuxpan	344	Altamira	751	Anguilla	83	Galveston	79	St._John's	351	St._John's	50
15	Port_Everglades	338	Bridgetown	686	Freeport(BHS)	83	Lake_Charles	75	Key_West	336	Bridgetown	40
16	Point_Lisas	299	Puerto_Cabello	645	Port_Arthur	71	Puerto_Cortes	74	Belize_City	278	Houston	36
17	Curaçao	281	Freeport(BHS)	611	St._John's	69	Puerto_Cabello	71	Fort_de_France	277	Guayanilla	33
18	Rio_Haina	247	Cristobal	607	Texas_City	65	Davant	70	Ocho_Rios	249	Cristobal	32
19	Tampa	242	Philipsburg	604	Galveston	65	Brownsville	70	St._George's(GRD)	234	Montserrat	29
20	Tampico	424	Port_au_Prince	572	Guayanilla	60	Port_au_Prince	67	Pointe_a_Pitre	226	Tortola	29
	Sum of listed top-20	11494	Sum of listed top-20	19967	Sum of listed top-20	3461	Sum of listed top-20	2978	Sum of listed top-20	10409	Sum of listed top-20	1569
	61% of the total	18816	60% of the total	33854	71% of the total	4877	61% of the total	4915	75% of the total	13895	70% of the total	2239

3.4 Future scenario with extended emission control

During the preparations of the application for the North American ECA, the US Environmental Protection Agency discussed (with the Mexico National Institute of Ecology, INE) a possible joint application with Mexico with the aim to include also the Mexican Gulf Coast in the ECA. Such an expansion, as indicated in figure 1, is considered as one plausible step of further expansion of the ECA in the WCR area.

In order to be eligible to submit an application to IMO for ECA designation of waters within the national economic zone, a country must be party to the MARPOL Annex VI. The list below indicates the present (August 2012) status of WCR countries that have ratified the Annex VI and thus are eligible to apply for ECA designations.

Table 4 – *WCR countries that are parties of the MARPOL Annex VI*

WCR Country	Ratified Annex VI	WCR Country	Ratified Annex VI
Antigua & Barbuda	✓	Jamaica	✓
Bahamas	✓	Mexico	
Barbados	✓	Netherlands	✓
Belize	✓	Nicaragua	
Colombia		Panama	✓
Costa Rica		Saint Kitts and Nevis	✓
Cuba		Saint Lucia	
Dominica		St. Vincent & Grenadines	✓
Dominican Republic		Suriname	
France	✓	Trinidad & Tobago	✓
Grenada		United Kingdom	✓
Guyana		United States	✓
Haiti		Venezuela	
Honduras			

Based on the list above and possible cooperation between geographically neighbouring countries it is possible that Bahamas would support an expansion of the North American ECA. If Mexico continues their preparation for ratification Belize would also possibly join a future application from Mexico for an expansion of the North American ECA.

Panama, Jamaica and Trinidad and Tobago are three key parties of the Annex VI and their roles in possible further expansion of the WCR ECA are important. It can be noted that Trinidad and Tobago's neighbours, Barbados and St Vincent and Grenadines, also are parties to Annex VI.

Close to the decided US Caribbean ECA covering Puerto Rico and the US Virgin Islands are the Annex VI parties Saint Kitts and Nevis and Antigua and Barbuda as well as the British Virgin Islands and British overseas territories like Anguilla and French and Dutch Territories, such as Saint Martin. Cooperation and possible joint application for ECA designation in this region may also be a possible scenario that would enable implementation of a relatively large and continuous Caribbean ECA.

In order to achieve a full ECA designation for the entire WCR it is, however, necessary that also the large island nations like Cuba, Dominican Republic and Haiti also actively support an ECA designation. Such a full WCR ECA would include large sea areas in the Caribbean Sea and the Gulf of Mexico and it would be larger and include more countries than the existing continuous Baltic Sea and the North Sea and English Channel SECAs.

The possible expansion options described above may be considered as plausible steps in a long-term development towards stricter global emission regulations for the shipping industry. In such a time frame it is also most likely that a number of new ECAs will be implemented in other parts of the world and the global world fleet will have to adapt to the strict emission regulations and designed or modified for compliance.

3.5 Technically feasible compliance strategies and options

Heavy Fuel Oil, HFO, is the dominating fuel type used for ship propulsion in the maritime industry. It is a residual fuel produced from refining of crude oil and generally has a sulphur content of about 3.5% by weight. This is 35 times more than the maximum allowed in the SECA in 2015. Marine Gas Oil, MGO, offers a fuel option for diesel-powered ships with sulphur content compliant to the SECA requirements. The price of MGO is, however, significantly higher than of HFO.

There are three main different compliance strategies identified and they are either based on a change of fuel type or the use of devices that purifies the exhaust emission after the combustion in engine.

- Change of fuel from HFO to LNG
- Change of fuel from HFO to MGO
- Continued use of HFO and installation of sulphur abatement technique/scrubber

Under MARPOL Annex VI, vessels may comply with the more stringent sulphur oxide (SO_x) and particulate matter (PM) emission regulations by using fuel oil with sulphur content below the prescribed limit of 1.0% and later 0.1% or by utilizing a "fitting, material, appliance or apparatus" such as exhaust gas cleaning technology. "Other procedures, alternative fuel oils or compliance methods" such as the onboard blending of fuel or the use of dual fuel (gas/liquid) may also be used, but such methods are subject to the approval of the vessel's Flag Administration and must be "at least as effective in terms of emission reductions as that required by this Annex".

Some basic aspects for comparison of the three main compliance strategies are listed in the table below with a ranking of pros and cons with regard to environmental performance and economic viability.

Table 5 – *Comparing the alternatives: LNG, MGO and HFO*

	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.

3.5.1 Gas engine options

There are basically two different concepts for using LNG as fuel in ship engines.

Dual fuel engines are able to run either on liquid fuel oil or gaseous fuel and can be designed either as four stroke engines or as two stroke engines. Single gas fuel engines are specifically designed for operation with gaseous fuel only.

Four stroke Otto-cycle Dual fuel engines

Dual fuel engines were developed for and are used in LNG carriers in order to utilize the boil off gas. LNG can be used as fuel when the ship is operating in a SECA and ordinary fuel oil can be used outside SECA and in regions where gaseous fuel is not available. The working principle for LNG operation is based on the Otto cycle and the Diesel cycle is the basis for operation on fuel oils. The ignition source during LNG operation is a small amount of fuel oil, which is injected and ignited by the compression heat and the burning oil ignites the gas injected at low pressure.

Two stroke dual fuel diesel engines

The two-stroke dual fuel technology applies high-pressure gas injection (about 300 bar) together with pilot diesel oil. The fuel oil ignites first and the gas is ignited by the burning fuel oil. This engine can run on fuel oil only or on a mixture of gas and fuel oil.

Single fuel gas engines

The Otto/Miller cycle is the basis for single fuel gas engines. Lean burn technology is applied in a spark ignition cycle. Instead of a pilot fuel, a rich gas/air mix in a pre-combustion chamber is ignited, which forms a strong ignition source for the very lean mixture in the cylinder. This technology ensures high efficiency and low emissions but does not allow the flexibility to also run on fuel oil.

3.5.2 Liquefied Natural Gas, LNG as fuel on board

LNG is expected to be available at competitive cost. It is a clean and non-sulphurous fuel. The gas engines have been proven to be reliable. Exhaust emissions such as SO_x and PM are negligible. NO_x can be reduced by approximately 80% to 90% for Otto cycle processes, and 10% to 20% for Diesel cycle processes. LNG contains less carbon than fuel oils, reducing the CO_2 emissions in a "from tank to propeller" perspective.

Methane is an aggressive greenhouse gas; an environmental drawback for Otto cycle process operation is the methane slip in the dual fuel engine. Technical development is progressing in this area and engine manufacturers claim that the methane slip issue will be reduced significantly in the future. If including the CO_2 and the methane emissions, LNG can still potentially give a reduction in greenhouse gases emissions compared to fuel oils (Danish EPA 2010). Methane slip is, however, not a problem for engines operating on gas in the Diesel cycle.

LNG is natural gas stored as liquid at −162°C. The predominant component is methane with some ethane and small amounts of heavy hydrocarbons. Natural gas is a fossil fuel but it can be mixed with or replaced entirely by biogas, which also consists mainly of methane. Due to the low temperature, LNG has to be stored in cryogenic tanks. LNG has a high auto ignition temperature and therefore needs an additional ignition source, i.e. a pilot fuel, to ignite in combustion engines. Natural gas is lighter than air and has a narrow flammability interval.

LNG storage tanks require more space than traditional fuel oil tanks. This may reduce the cargo capacity, depending on type of vessel, type of fuel tank and potential of adequate location of the LNG tanks on board.

The reduction of cargo space was examined within a GL study of the retrofit from HFO to LNG of the CV Neptun 1 200 design. Due to the LNG tank dimensions the container capacity of 1 284 TEU would be reduced by 48 TEU to 1 236 TEU.[6]

Another example is shown by the first retrofit worldwide of a seagoing vessel, the tanker **BIT VIKING**. The two LNG fuel tanks with a capacity of each 500 m^3 LNG are located on deck with no actual reduction of the cargo capacity. Due to the properties of LNG and gaseous natural gas, special requirements for the tanks and the fuel supply system need to be fulfilled.

3.5.3 Marine Gas Oil, MGO – Low sulphur diesel oil

Heavy Fuel Oil (HFO) or residual fuel oil is the heaviest marine fuel with respect to viscosity and sulphur content. Distillate fuels can be further divided into two categories, Marine Gas Oil (MGO) and Marine Diesel Oil (MDO). When residual fuel oil is blended with distillates, the blend is called Intermediate Fuel Oil (IFO).

It is theoretically possible to desulphurize HFO and produce HFO with 0.1% sulphur but in practice the most viable solution is to use MGO when a new fuel oil quality is chosen for compliance to SECA regulations. If the refineries will get a surplus of HFO it is likely that it will be refined by cracking processes, etc. to MGO.

MGO with 0.1% sulphur or less is readily available and has similar properties as diesel fuel used for high-speed diesel engines. The viscosity of MGO is lower than for MDO or HFO and for operation in two stroke marine diesel engines the fuel may need to be cooled to stay at specified engine design viscosity levels to prevent fuel pump wear, etc. Swapping from heated HFO to cooled MGO when entering a SECA needs to be done with due care to the actual fuel viscosity in particular for conventional engines without common rail systems. For long-term shift of fuel, it may also be necessary to exchange the lubrication oil for another quality.

In addition to reduced SO_x emissions, particulate matter in exhaust gases is also reduced. NO_x and greenhouse gases will remain at the same level as when using HFO. In order to comply with NO_x Tier III, SCR or EGR are needed when operating on MGO. MGO does not require extra volume for storage tanks, nor is retrofitting of

[6] GL Scholz & Plump.

the engine required; hence no or only minor investments are needed for a switch to MGO operation. The fuel price for MGO is, however, significantly higher than for HFO.

3.5.4 Other alternatives

Beside low-sulphur fuel oils, exhaust gas cleaning and LNG there are other alternative fuels that are considered within the current development of the IGF Code. These fuels are, e.g. LPG, DME/methanol, ethanol and hydrogen and will be allowed after ratification of the IGF Code in 2014.

3.5.5 Exhaust Gas Scrubbers

Abatement technologies, or 'end of pipe' solutions, include primarily use of scrubbers for the SO_x and PM removal in combination with either Selective Catalytic Reduction (SCR) or Exhaust Gas Recirculation (EGR) for NO_x cleaning. This combination is considered to have good prospects to fulfil the requirements in SECA 2015 and ECA Tier III. It is possible that Tier III NO_x requirements may be fulfilled even without applying SCR technique.

The main advantage of the scrubber technology is that readily available high sulphur HFO can be used, thereby keeping the fuel costs down. The infrastructure, hence the availability, of HFO is also good and the ship owners do not need to retrofit or replace the engines. Scrubber tests show that the sulphur emissions are reduced to almost zero and a significant reduction of PM in the exhaust gases is also achieved.

In addition to the necessary capital investment in scrubber devices on board, the waste produced by operating the scrubber need to be handled and discharged in port. At present there is no infrastructure established in ports for reception and disposal of scrubber waste. Such infrastructure may be established in parallel with other established reception routines and facilities used for reception of ship generated sludge, garbage and sewage. A fee system for reception of scrubber waste must be designed not to create disincentives for safe delivery ashore by undue delay or costs.

Different technical solutions are available for scrubber technique and these vary in terms of e.g. cost, on board space requirements and waste quantities produced. For the scrubber compliance strategy, high scrubber availability is important.

3.6 Economically viable compliance strategies

The strategy to switch from HFO to MGO operation will increase the operational costs significantly, essentially in proportion to the price difference between HFO and MGO but it is not associated with any major reconstruction efforts or investment costs on board. The existing bunker supply infrastructure generally offers both HFO and MGO to their ship clients and is not expected to undergo any dramatic modifications except for the relation between delivered HFO and MGO quantities.

Continued use of HFO and installation of scrubber is associated with significant investment costs for scrubber and related equipment but operational cost will only be marginally affected by slightly increased fuel consumption and by consumption of process chemicals. The investment costs will differ between retrofit installations and new build projects.

For LNG operation, ordinary diesel powered vessels will require major reconstruction works including engine and LNG tanks; new builds will also be associated with higher costs if equipped with dual fuel or LNG engines and LNG fuel tanks. A most important factor for economic viability of the LNG fuelled ship is the price of LNG bunker for the ship owner (FOB) and its relation to FOB price for conventional fuel oils.

3.6.1 Investment cost for the different compliance strategies

The investment cost differs for the different compliance strategies, for retrofit or new builds and is partly proportional to the size of the propulsion plant. The table below has been prepared by compilation of price information from different engine manufacturers and shipyards; a detailed version was presented in the DMA study, appendix 3 (DMA 2012).

Table 6 – *Indicative investment costs for optional compliance strategies*

Compliance strategy	Retrofit	New builds
MGO – engine conversion, SCR and EGR	180 000 USD + 75 USD/kW	140 000 USD + 63 USD/kW
HFO and scrubber – scrubber and SCR	600 USD/kW	2 200 USD/kW*
LNG four stroke dual fuel – LNG tanks etc.	800 USD/kW	1 600 USD/kW*
LNG two stroke high pressure dual fuel – tanks etc.	700 USD/kW	1 500 USD/kW*
LNG four stroke spark ignition – LNG tanks etc.	800 USD/kW	1 600 USD/kW*

* including engine, generators, etc.

When a ship operator is going to choose compliance strategy it is essentially a matter of balancing high investment costs for retrofitting of new equipment or in new build projects versus long-term operational costs depending on the type of fuel selected. In addition to these basic calculations there may be other factors that also need to be considered, for example bunkering LNG may take longer than bunkering fuel oils, a need for extra education of the staff, requirements for special licences and certificates. Extra costs may arise due to loss of available cargo space due to the need for extra space for LNG tanks. This may be particularly relevant for container ships but less important for other ship types like tankers.

For the scrubber compliance strategy, high scrubber availability is important as well as a port infrastructure for efficient reception of scrubber waste.

MGO is considered to be an attractive "wait-and-see" strategy with low investment costs for actors who believe that LNG may have a breakthrough sometime in the mid-term future. However, if many actors use that strategy, the MGO demand, and hence price, may increase further.

3.6.2 Operational costs – fuel price and price predictions

The energy content and densities vary between different fuel oil qualities and depends on the specific composition of the LNG. It is therefore important to take into account these differences when price comparisons are made for various fuel types and compliance strategy costs. For the price comparisons discussed below, the following figures in SI-units are considered representative and used as typical values for correction of comparisons.

Table 7 – *Representative physical and energy characteristics of optional ship fuels*

Fuel	Density kg/m^3	Specific Energy GJ/tonne	Correction factor
MGO	850	46	1.07
HFO	990	43	1
LNG	450	54	1.26

The price for HFO and MGO as well as the LNG price vary a lot and have traditionally been relatively well correlated to the crude oil market price. The price characteristics also differ from different areas in the world, for example the bunker fuel and LNG prices differ between Europe and the WCR.

From the ship owners' perspective it is the relative relation between the optional fuels (MGO or LNG) and the traditional HFO that is important. The figure below shows the relations LNG/HFO and MGO/HFO in Europe over a period of eight years. The curves are corrected to represent the price per unit of specific energy relation and show a magnitude of 50% higher price for MGO and about 40% lower price for LNG compared with HFO. In the US Gulf area, the LNG/HFO ratio is significantly lower.

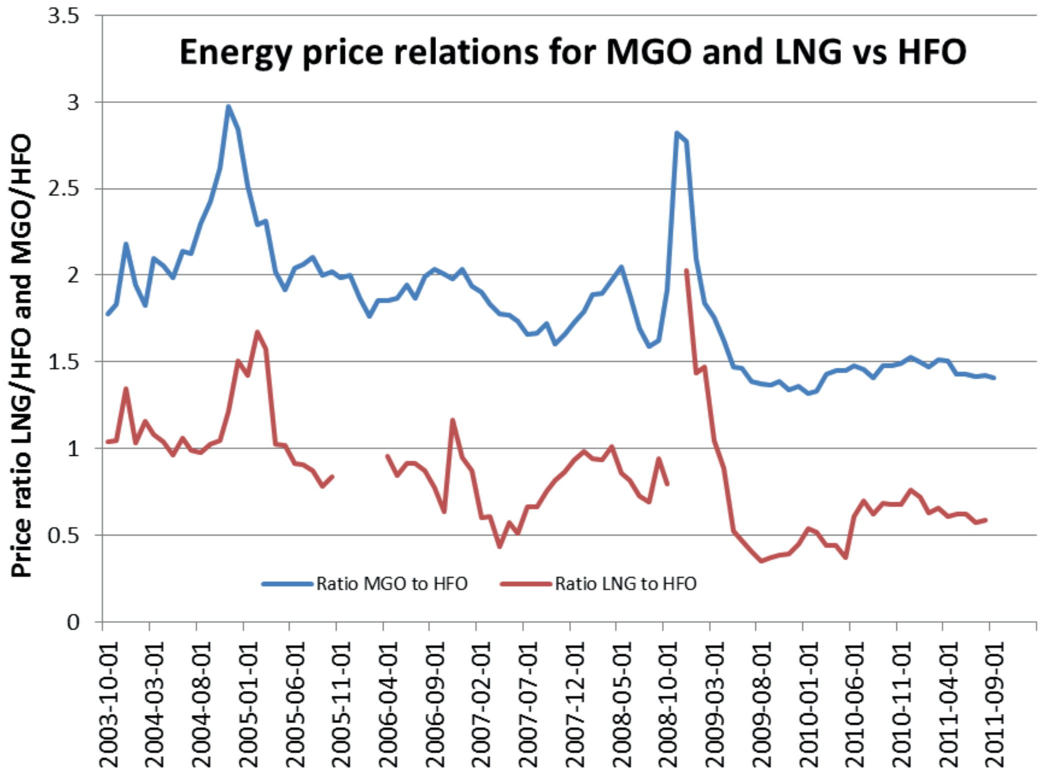

Figure 39: *MGO price relative to HFO and LNG price relative to HFO. Prices are at European import Hub and based on prices per GJ. Source: AF analysis, 2012 (DMA 2012)*

Due to the expansion and shale gas production during recent years in the USA, today's gas price in North America is significantly lower than in other parts of the world. The Henry Hub Index reflects the gas price in the US market and the figure below illustrates how the gas price differences have increased over the last year and how the JKM index representing the Japanese market increased significantly after the Fukushima power plant disaster in March 2011. The red NBP index is representative for the European market and is indicated at an order of 2–4 times higher than the Henry Hub figures.

The low Henry Hub gas price will of course also influence the market price for LNG as ship fuel (FOB) in the American Gulf ports and in the entire WCR when it is introduced as a fuel option. Compared with the European situation, where feasibility studies for introduction of LNG as ship fuel also have been conducted, this price relation clearly indicates that the attractiveness of swapping to LNG with respect to the operational cost is higher in the WCR than in Northern Europe.

If ships equipped with LNG dual fuel engines may choose between HFO or LNG operation outside SECAs, and the LNG/HFO energy based price relation is lower than 1, LNG will turn out to be the economically best option also when operating outside SECAs.

The production of shale gas is expected to increase in the USA and even if the export of gas will increase from the US it is anticipated that the gas price at the US market will stay at a low level. It is also considered likely that the future gas price will be less correlated to the crude oil price as it traditionally has been.

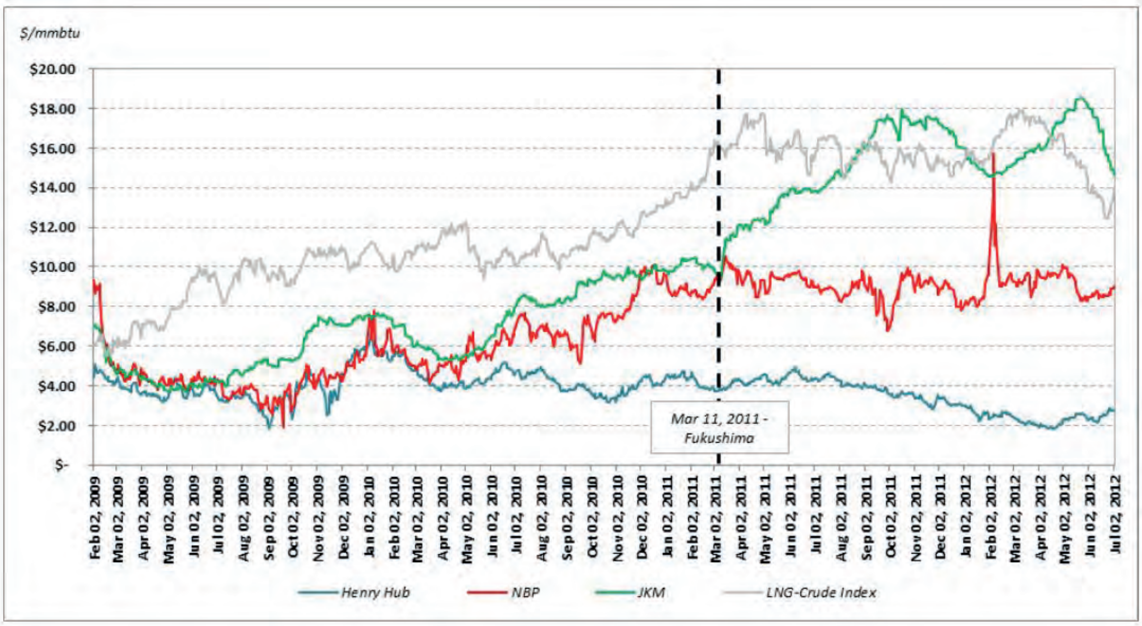

Figure 40: *Time history plot of LNG price comparison (USD/MMBtu) between USA (Henry Hub), Europe (NBP) and Japan (JKM). Diagram excerpted from Medlock 2012 based on data from Platts, US EIA and Medlock*

4
Infrastructure

In addition to USA there are five main natural gas-producing countries in the WCR but only one LNG producer. The natural gas production capacity has increased significantly in Trinidad and Tobago and in Mexico over the past decade. In Venezuela, the production has decreased while Colombia and Cuba show a moderate increase of their production capacity. The situation is illustrated graphically in the figure below.

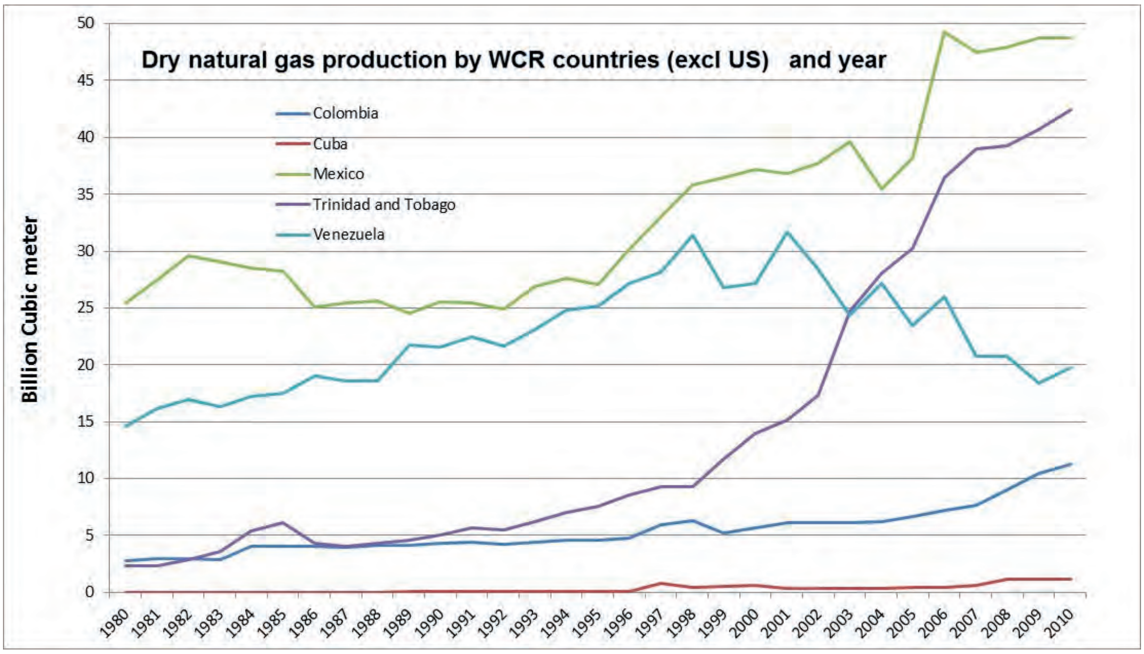

Figure 41: *Development of dry natural gas production in the WCR countries (excluding USA) (BP 2012)*

The produced natural gas is traded between different WCR countries and exported as LNG from liquefaction plants and LNG tanker terminals to LNG import terminals with regasification plants and, in the future, possibly to facilities for distribution of LNG to land based consumers and to ships. The figure below shows that Trinidad and Tobago is the main exporter and that USA the main importer of LNG, though it also has a minor export volume in 2011.

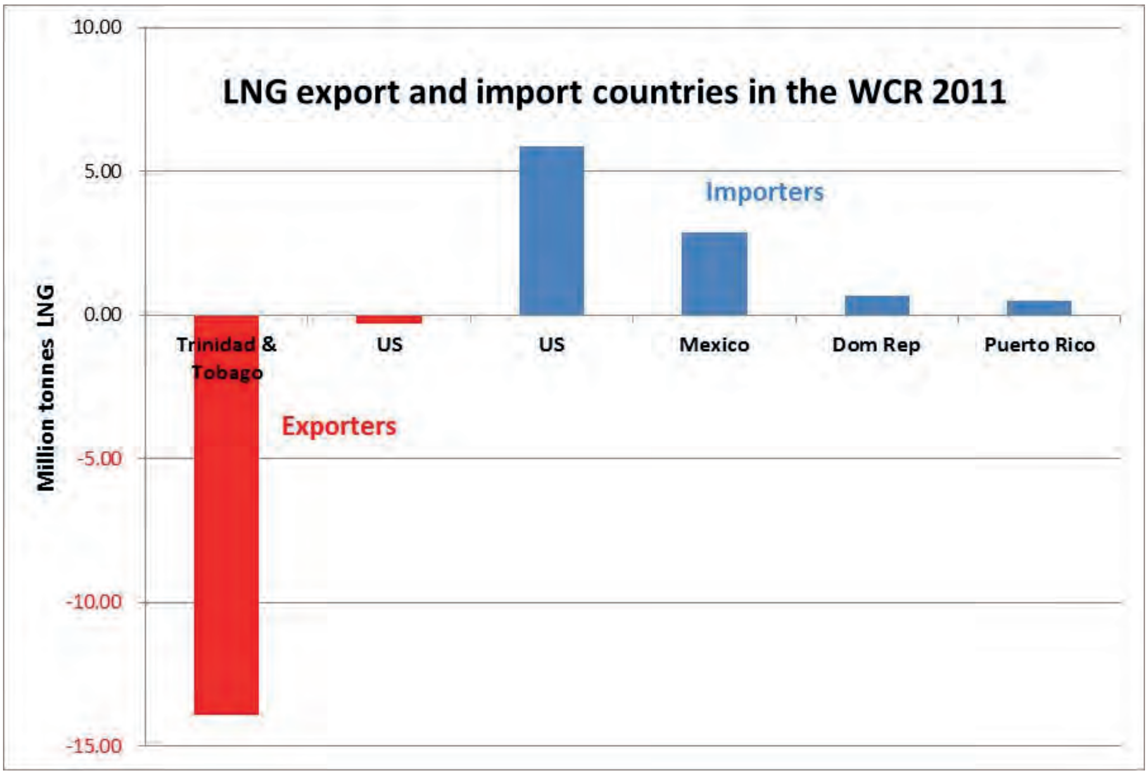

Figure 42: *The balance between LNG export and import in the WCR countries in 2011. Note that one of the two Mexican import terminals is located on the Pacific side outside the WCR (BP 2012)*

4.1 LNG Infrastructure in the Caribbean

The LNG market is expected to grow in the Caribbean region due to several factors that make it a more attractive energy fuel compared to oil-based fuels. Traditional oil-based fuels account for 95% of the Caribbean energy (Battistini, 2011). The current most widely used fuel product in the region is HFO.

The Caribbean countries are vulnerable to oil price volatility because of their high dependence of oil to generate most of their electricity in addition to vehicle fuel. Some islands are discussing a shift from oil to natural gas as a response to recent oil prices (Kitasei & Adkins, 2011). Reducing the dependence on oil is considered urgent to stimulate economic development, attract industries and improve life quality (Pereira, 2012). As long as the price differential between LNG and HFO remains large, USD 0.04/kWh (USD 12.10/MMBtu) for HFO and USD 0.02/kWh (USD 4.88/MMBtu) for natural gas (in 2010), it is likely that many Caribbean nations will try to replace oil by natural gas (Kitasei, 2011).

Currently there are on-going studies on the potential for development based around domestic renewable energy and energy efficiency resources in the Dominican Republic, Jamaica and Haiti (Kitasei & Adkins, 2011). LNG is a good alternative, even if it most likely would have to be imported. While LNG may be an appealing alternative, significant capital investment is required, both for construction of import terminals and infrastructure.

Natural gas consumption is increasing in the area, as is the interest in and potential of small-scale LNG projects in the region. Since LNG transports are no longer restricted to large vessels, due to new technologies, small-scale LNG is preferred over large-scale projects (Battistini, 2010).

Puerto Rico began importing LNG in 2000, and the Dominican Republic has a LNG regasification terminal supplying a gas-fired power plant (Andres). Jamaica currently has no LNG import facilities, but the government has shown interest in building one and has already reached an advanced stage in the development of an LNG project. Barbados, together with Jamaica, is also on the way to make a switch for natural gas as their premier fuel source. Barbados plans to start importing natural gas via pipeline from Trinidad and Tobago from 2015 (Caribbean360, 2012).

LNG in the Caribbean is likely to be supplied by imports from Trinidad and Tobago, the largest gas producer, and today also the only existing liquefaction LNG plant and export terminal in the Southern Caribbean region.

It is the 11th largest natural gas exporting country in the world as well as the largest exporter of LNG to the US. In 2011, Trinidad and Tobago produced 40.7 billion m^3 of natural gas (BP 2012).

Several LNG liquefaction terminal projects and LNG regasification terminals have been proposed, or are under construction in the region, for example in the Bahamas, Venezuela, El Salvador and Honduras (CEC, 2010). Around 30 floating regasification projects are planned worldwide; Asia and the Middle East account for 16 and South America six. Europe and Africa make up the majority of the remaining FSRU demand.

4.1.1 Overview of planned and existing LNG facilities in the WCR

The map below indicating the locations of existing and planned LNG facilities is compiled from various sources and more specific data referring to the indicated spots on the map is given for each country in the text sections below.

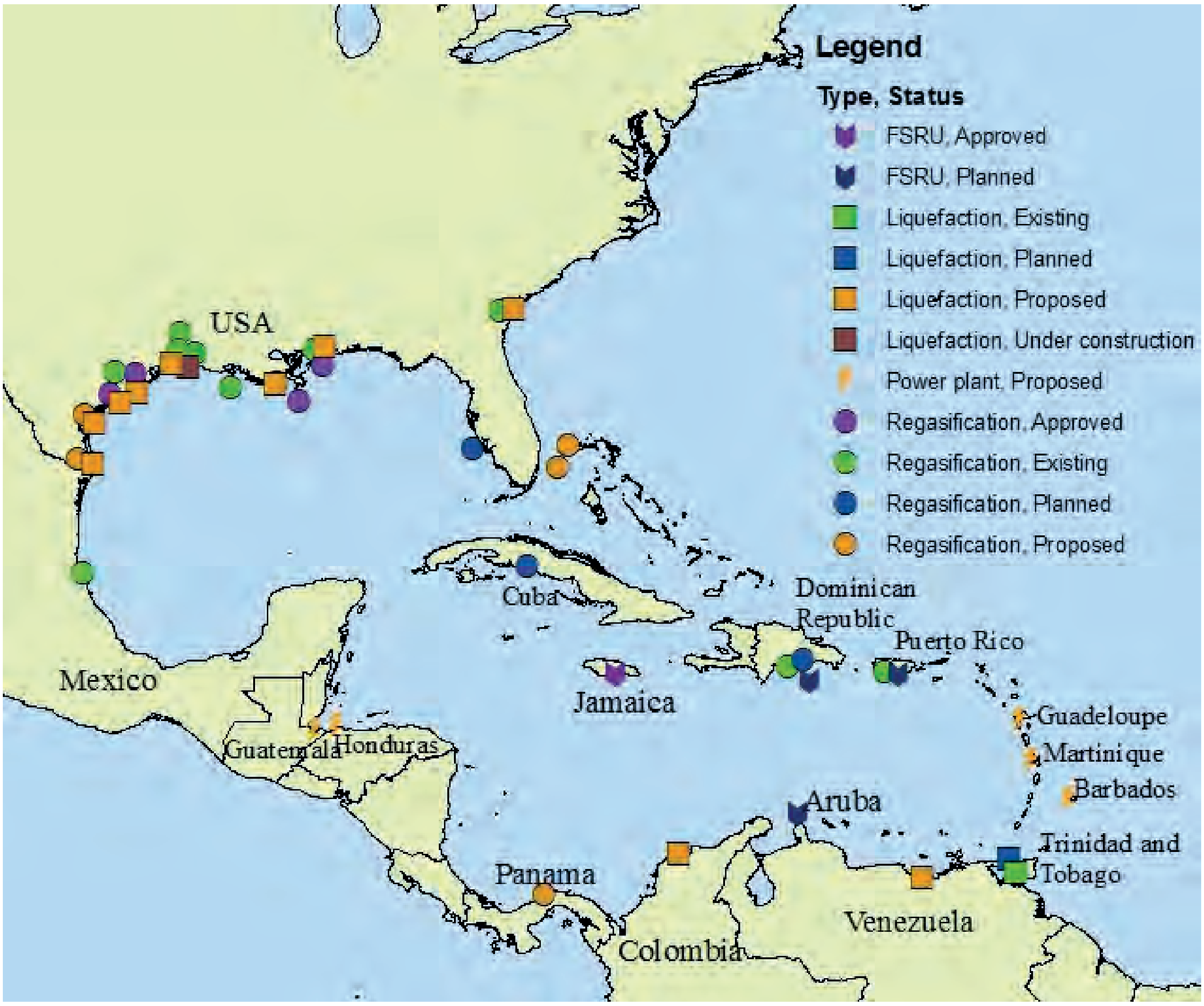

Figure 43: *Overview of planned and existing LNG facilities in the WCR*

The table below summarizes the available data of the facilities and plants indicated in the map above.

Table 8 – *Existing and planned LNG facilities and plants in the WCR*

Country	Type of LNG plant or facility	Status	Capacity
Aruba	FSRU	Planned	Send out capacity of 0.7 – 3.0 million m^3 gas per day
Bahamas	Import and regasification	Proposed	Import from Trinidad. Containerized import from USA
Barbados	Subsea gas import pipeline	Planned	300 km pipeline. 30 million m^3 natural gas per day.
Colombia	FLRSU (bi-directional plant)	Planned	Liquefaction capacity 500 000 tonnes of LNG per annum
Costa Rica	Regasification plant	Proposed	Not specified
Cuba	Import and regasification	Planned	Import from Venezuela. 1 million tonnes LNG per year
Dominican Republic	Andres import – regasification San Pedro import/regasification	Existing Planned	0.9 billion m^3 of natural gas imported in 2011 Send out capacity of 7–20 million m^3 gas per day
Guatemala	200 MW gas fired power plant	Proposed	Not specified
Honduras	LNG import for power plant	Proposed	Not specified
Jamaica	FSRU	Planned	Not specified
Martinique & Guadeloupe	FSRU	Planned	Regasification of 400 000 tonnes of LNG per year
Mexico	Altamira, Import-regasification	Existing	Can be expanded to 10 billion m^3 of natural gas per annum
Panama	Import and regasification	Planned	Initial send out capacity 40 million m^3 natural gas per day
Puerto Rico	Guayanilla Bay FSRU Aguirre Gas Port FSRU	Existing Planned	Send out capacity of 1 200 million m^3 per annum Send out capacity of 6 500 million m^3 per annum
Trinidad and Tobago	Atlantic LNG liquefaction plant and export terminal	Existing Planned	LNG export corresponds to 19 billion m^3 of natural gas A fifth liquefaction train is planned
USA	12 LNG import facilities 3 LNG export terminal in WCR	Existing Approved	Import 11.6 billion m^3 natural gas in the form of LNG 2010 Export 3 million m^3 LNG (1.1 Bcf) per day in 2016
Venezuela	LNG liquefaction plants, 3 sites	Proposed	LNG production, 2 800 billion m^3 natural gas per year

4.1.2 Aruba

US Valero Energy and the government of Aruba are investigating possibilities with LNG with the intention of a joint venture between Valero, the Water & Energy Company WEB, and the Dutch Gasunie in which the refinery and WEB are to use gas instead of petroleum for their production while at the same time setting up a regasification terminal for supply (Amigoe, 2011b). An FSRU unit is considered the best solution in the short term, although an LNG import terminal is examined as an option. Due to possible offshore gas reserves, a temporary floating solution is a better option meanwhile (Meredith, 2012). In the long term a land-based LNG terminal or a gas pipeline from the South American coast (Venezuela) may be a replacement for the FSRU (Martin, 2010).

The send-out capacity of the FSRU will be 700 000 m^3 natural gas (25 million cf) per day to solely supply the power plant. This could be increased to 3 million m^3 natural gas (100 million cf) per day if the refinery stays in operation (Meredith, 2012c).

Two Dutch companies, Anthony Veder and Gasunie, are engaged in developing a business case for a small-scale FSRU, cost estimated and the best location, together with the government controlled Utilities Aruba. Gasunie will be responsible for the terminal infrastructure and Anthony Veder for LNG transports, should the government decide to go ahead with the project (Meredith, 2012c).

4.1.3 Bahamas

The Government of Bahamas is interested in introducing LNG and CNG as an alternative energy source (Smith, 2012). Three companies have long been interested in establishing LNG plants: AES Corporation, Tractebel and El Paso. Proposals to build LNG regasification terminals in the Bahamas have been investigated aiming to send natural gas imported from Trinidad to Florida via an undersea pipeline, diverting some of the gas to power plants in the Bahamas. The regasification terminals were proposed on either Ocean Cay (near Bimini) or Grand Bahama.

A Florida licensed firm has investigated the possibilities for export of smaller quantities of LNG to the Bahamas and other countries in the region in containers. The gas would be exported in special cryogenic tanks fitted inside 40-foot shipping containers (Smith, L., 2012).

4.1.4 Barbados

In Barbados plans have been presented for supply of natural gas from Trinidad and Tobago via construction of a pipeline. Originally the project was planned to start in 2013 to be completed by 2015. The pipeline project will involve a 300 km long pipeline running from the Cove Point Estate in Tobago to Barbados, supplying the Barbados Light and Power Company, the only electrical utility on the island, with 30 million m^3 natural gas per day. US-based Beowulf Energy LLC and First Reserve Energy Infrastructure Fund will construct the pipeline (Caribbean360, 2012).

4.1.5 Colombia

On the northern coast of Colombia, Exmar plans an export terminal together with Pacific Rubiales. Construction of a barge-based, bi-directional floating liquefaction, regasification and storage unit (FLRSU) has already started at a shipyard in China, the first of its kind. The South American operator Pacific Rubiales is expecting an environmental licence for an 88 km long pipeline to transport gas from the onshore La Creciente field to planned location of the FLRSU (Martin, 2012e). The project will have a 14 000 m^3 LNG onboard storage and a 140 000 m^3 LNG carrier will be moored alongside to be used as a floating storage unit. The project is set to be in operation by the end of 2014 (Meredith, 2012d). Exmar will build, operate and maintain the FLSRU. It will be fitted with type-C storage tanks and can be scaled up to 30 000 to 40 000 m^3. The whole floating terminal will be able to supply vessels of 150 000 to 160 000 m^3. Liquefaction capacity is approximated to around 500 000 tonnes of LNG per annum. Two small LNG carriers will be used to supply Caribbean customers that will use barge-based regasification for their imports (Hine, 2012d).

4.1.6 Costa Rica

Diesel fuelled power generation, public transports and freight are to be replaced with natural gas in Costa Rica and the results from an economic and technical feasibility study is awaited. In order to use natural gas a gasification plant is required. According to preliminary figures, a gasification plant would cost about USD 75 million and the funding remains to be defined (Centralamericadata, 2012c).

4.1.7 Cuba

Cuba is about to introduce LNG in the country's energy mix. All natural gas production in the country is oil-associated. Approximately 1.2 million m^3 of associated natural gas is produced per year (2010). Associated natural gas production is being used as fuel for onsite power generating plants of 400 MW total capacity. An LNG regasification facility to receive Venezuelan-sourced LNG is currently being planned for the southern coast port city of Cienfuegos. Two regasification trains of 1 million tonnes have been planned for 2012 at a cost of over USD 400 million.

The Carlos Manuel de Cespedes electric power plant in Cienfuegos is in the middle of an upgrading process that allows the burning of natural gas. Natural gas will provide fuel to the refinery as well as hydrogen for the upgrading units scheduled to be completed by 2013. Natural gas will also be used as a feedstock for a planned USD 1.3 billion petrochemical (Piñón, 2010).

4.1.8 Dominican Republic

The Dominican Republic was the second island in the Caribbean to establish an LNG import terminal and a second terminal is now planned.

Andres terminal

The Andres terminal is a combined 319 MW gas-fired power plant and import terminal, built according to US standards. It was constructed in 2003 and is located 35 km east of the capital Santo Domingo. Storage capacity is 160 000 m^3 LNG (A Barrel Full, 2012).

The Andres import terminal is designed to receive LNG from ships with capacities ranging from 35 000 to 145 000 m^3. The regasification terminal is primarily supplied with LNG from Atlantic LNG's Train 4 (Meredith, 2012c). Since 2008, gas has been offered for industrial customers to be used instead of diesel in boilers and other factory processes. As a result many factories today get LNG delivered by truck from the terminal through distribution companies. In addition to industrial use, natural gas has also been used as transport fuel (Suvusari, 2011). LNG demand in the Dominican Republic has risen 40% between 2009 and 2012 (Meredith, 2011). Imports through the terminal are expected to continue to increase due to customers forecast consumption and contract negotiations; however, current infrastructure is assumed sufficient to supply the anticipated demand (LNG Unlimited, 2011).

San Pedro de Macorís

AES has been contemplating building another 160 000 m^3 regasification terminal to enable it to supply gas onwards to other parts of the Caribbean. Foster Wheeler's subsidiary of its Global Engineering and Construction Group was awarded the basic design and front-end engineering design (FEED) contract by Complejo GNL del Este[7] for a new LNG receiving terminal and jetty. The terminal will be located in San Pedro de Macorís and is designed to handle a send-out capacity of 7 million m^3 natural gas per day (249 MMcfd), with future expansion possibilities up to 20 million m^3 per day (700 MMcfd). The FEED is expected to be completed in September 2012 (Hine, 2012).

San Pedro de Marcoris is also the site of a floating terminal project, a result of a joint venture between BW Gas and InterEnergy Holdings, expected to be finished in 2014 (Dominican Today, 2012). The project is not affiliated with the land-based LNG terminal project. BW Gas has knowledge regarding business of transportation and storage of natural gas while InterEnergy has experience in the country's energy sector (Dominican Republic Live, 2012).

BW Gas is considering three different solutions for a floating LNG import terminal and the technology for the job has yet to be determined.

Figure 44: *Natural gas fuelled power barge for generation of electricity moored in the city centre of Santa Domingo and supplied by gas from the Andres LNG import terminal and regasification plant*

4.1.9 Guatemala

Natural gas is not used in Guatemala but interest is growing for possibilities of its use in the country. Necessary infrastructure is needed to allow optimal storage tanks as well as pipelines. A tender is scheduled to be

[7] Complejo GNL del Este is a consortium of Dominican and Colombian companies that participate in the energy sector of those countries.

released in the last quarter of 2012 for the installation of a 200 MW power plant to generate electricity from natural gas. The start of operations could be in 2015. Studies have indicated Puerto Barrios as a suitable location for the installation of the natural gas power plant (Centralamericadata, 2012 and 2012b).

4.1.10 Honduras

A multi-disciplined marine investigation has been performed in the waters off Puerto Cortes in the Gulf of Honduras, including hydrographical, geophysical, oceanographic, meteorological and biological aspects. The aim of the investigation was to collect scientific data in support of the design of a proposed power plant, owned by AES Honduras, and marine terminal expansion on the west shore of the Cortes peninsula. The power plant will provide service to much of Honduras with transmission into El Salvador as well. The plant requires construction of cooling water intake and discharge pipelines, coastal protection structures and a pier facility for offloading LNG that will be used to power the plant (Ocean Surveys, 2005).

4.1.11 Jamaica

Jamaica has been exploring the potential for importing LNG since 2001.

In 2009 the Petroleum Corporation of Jamaica requested proposals for an FSRU and in 2010 a consortium led by Exmar was selected as a preferred bidder to finance, build, own and operate the terminal. The project was, however, retendered (Meredith, 2011b). Part of the delay for the LNG project is a result from uncertainties over gas supplies (The Gleaner, 2012).

The FSRU terminal is currently set to supply three main customers. The Jamaican Public Service Company (JPS) is the country's major power utility, demanding 360 MW. The second is Jamaica Energy Partners (JEP), an independent power producer requiring conversion of existing 125 MW Power Barges, and last, Jamalco, a bauxite mining and aluminium refining company.

The South Korean company Samsung was chosen as the preferred bidder in July 2012 to develop Jamaica's first FSRU unit for LNG, including necessary infrastructure (The Gleaner, 2012b).

The Jamaica Gas Trust (JGT) was established to be the legal counterpart, a contractual focal point of the LNG and will act as a sole LNG purchaser for the project. It will be financed with USD 100 million and managed by the private sector (The Gleaner, 2012). Its objective is to execute the major commercial agreements, including LNG sales and purchase agreements, terminal and transportation agreements (MSTEM, 2012). The single stage RFP for an FSRU construction in the Port Esquivel area was announced in June 2012 and the target start date is approximated to 2014 (GoJ, 2012b).

4.1.12 Martinique and Guadeloupe

French EDF (Electricité de France) is investigating options to supply their power generation plants in Martinique and Guadeloupe with natural gas. A team building with Gasfin Development resulted in the launch of a project to supply 400 000 tonnes per annum to two Caribbean power plants. FEED studies as well as permitting of import infrastructure are on the way, including gas delivery infrastructure to support transportation, storage and regasification. A newly built mid-scale LNG carrier and two purpose-built floating storage and regasification units are to be developed for the project (Meredith, 2012d). LNG sourced from one of the regional LNG terminals will be delivered by the LNG carrier to the FSRUs moored in the vicinity of the power plants. The LNG will be stored and regasified on the FSRUs, then sent to the respective power generation facilities via a short subsea pipeline (TGE Marine, 2011).

4.1.13 Mexico

Mexico has long relied on natural gas as a feedstock for its petrochemical manufacturing facilities. For home heating and cooking LPG is used. There are no LNG liquefaction plants in Mexico, and only one regasification terminal on the Gulf Coast, Terminal de LNG de Altamira (CEC, 2010c). Altamira could be expanded to 10 billion m^3 per annum, with the addition of a third storage tank (Meredith, 2011c).

Several additional LNG regasification terminal projects are either under construction or are proposed.

4.1.14 Panama

Introduction of natural gas is negotiated between Repsol (Spain) and Panama's CNG Clean Energy. First, construction of facilities for regasification of LNG and a storage vessel to be moored in Bahía de las Minas, on the Caribbean coast, is required. The location is very near the complex of power plants that have been operating in the area with petroleum and coal.

The regasification terminal is estimated to cost USD 250 million in the period 2011 to 2014 and operations are planned from the first quarter of 2014 providing an initial volume of 40 million m^3 natural gas per day (Centralamericadata, 2011).

4.1.15 Puerto Rico

Guayanilla Bay

An existing LNG import facility is located at Guayanilla Bay, Peñuelas. The facility began operations in 2000 and the gas powers a 461 Megawatt cogeneration plant, which sells electricity to Puerto Rico Electric Power Company (accounting for 20% of the generated electricity on the island). The facility consists of a marine terminal with a 550 metre pier for unloading LNG 160 000 m^3 LNG carriers and regasification plants with a send out capacity of 1200 Bm^3 natural gas (33,9 Bcf) per year.

In addition to the FSRU there are plans to build pipelines. The Vía Verde natural gas pipelines would run in a south-north direction from the city of Peñuelas, existing LNG import terminal, to Arecibo, then east to San Juan, in total 145 km (Periera, 2012). The planned pipeline project will supply the north coast power plants. The Puerto Rico Government, however, are focusing on the south coast project because the FSRU is assumed to get a quicker federal approval and it could supply sufficient natural gas to partially supply the fuel needed to convert the power plants on the north coast.

The establishment of a "satellite" facility in San Juan to receive shipments of LNG from the south is an alternative. The FSRU would have enough excess capacity to satisfy the demand. It is possible to ship 2.5 million m^3 natural gas per day by barges, sufficient to supply units 5 and 6 of the San Juan power plant (Marino, 2012).

Aguirre GasPort

Development and permitting of an FSRU is in an executed agreement between US-based Excelerate Energy and PREPA, the Puerto Rico Electric Power Authority. The Aguirre GasPort terminal is planned 6.5 km off the southern coast of Puerto Rico, near the towns of Salinas and Guayama, and will provide fuel to the existing Central Aguirre power plant. The power plant has already converted 600 MW of possible 1500 to utilize natural gas and will convert the total capacity once the FSRU project is completed.

Aguirre GasPort will offer year-round service and supply. It will be the seventh FSRU delivered by Excelerate Energy worldwide, thus using proven technology with facilities to receive, temporarily store, vaporize and deliver up to 18 million m^3 natural gas per day. LNG will be delivered to the project via LNG carriers, unloaded and stored within a permanently docked FSRU unit and delivered directly to the Aguirre Plant by a subsea pipeline.

Construction of the 150 900 m^3 FSRU is expected to start in 2013 and planned to be in service in 2014 (A Barrel Full, 2011); however, authorization is required from the FERC (Federal Energy Regulatory Commission) together with a full public environmental review and analysis under the National Environmental Policy Act. Capital costs for the floating terminal are in a range of USD173 million (Hine & Meredith, 2012). The Aguirre Offshore GasPort will consist of two main components: 1) an offshore marine LNG receiving facility consisting of an FSRU moored at an offshore berthing platform; and 2) and a subsea pipeline connecting the offshore terminal to the Aguirre Plant.

The offshore terminal will be designed for long-term mooring of an FSRU and for receipt of LNG carriers ranging from 90 000 m^3 up to a Q-Flex2 size (216 000 m^3) LNG carriers.

LNG supply tenders for the FSRU are in progress. The required supply volumes have yet to be decided and depend on the supply contract (Hine & Meredith, 2012).

4.1.16 Trinidad and Tobago

Trinidad and Tobago holds the position of largest single LNG supplier to the US and sole provider of LNG to the only two Caribbean established markets that are equipped to receive it – Puerto Rico and the Dominican Republic – although several nations are exploring FSRU as an option for import of LNG (Renwick, 2011).

The Boston based company Cabot LNG initiated an LNG project in 1992, setting the ground for the Atlantic LNG project that exists today. Cabot was joined by Amoco, BG and the National Gas Company of Trinidad & Tobago (NGC) and, later on, by Repsol.

Sales contracts were signed with Cabot and with Enagas of Spain in 1995 for a total of 3 million tonnes per annum (mtpa) of LNG. Construction started in 1996. The first cargo, bound for Boston, was loaded at the end of April 1999. Design work and sales negotiations for a two-train expansion were started in early 1999 and construction started in 2000.

In 2009 there were four active trains (Atlantic LNG, 2012), a rapid development by the standards of LNG projects and judged a success for all parties involved, compared to previous LNG projects (Shepard & Ball, 2004). It should be noted that Suez has recently announced the sale of their share in Train 1 to the China Investment Corporation (Algell).

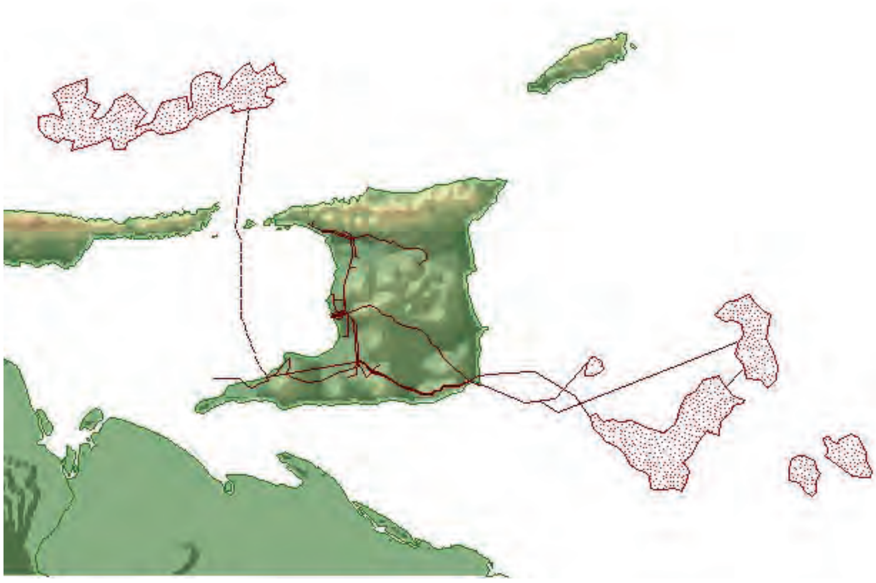

Figure 45: *View of gas fields linked to Trinidad and Tobago*

The Atlantic LNG plant in Point Fortin is the only current operating liquefaction facility in the Caribbean region. The plant, located on the southwest coast, is supplied by different gas fields off the Trinidad and Tobago coast via dedicated pipelines.

The liquefaction plant uses two storage tanks (Train 1), each with 105 000 m^3 LNG capacity and a 700 metre-long jetty, which are capable of accommodating LNG carriers with a capacity of up to 135 000 m^3. Trains 2 and 3 demanded an extra 160 000 m^3 storage tank and an extra loading arm to the jetty (Shepard & Ball, 2004). Train 4 began operations in December 2005 (MEEA, 2009). The total production capacity of the four trains is around 15 million tonnes of LNG per year (mtpa); the capacity of Train 1 is 3 mtpa and the capacity of each of Trains 2 and 3 is 3.3 mtpa. Train 4 has a production capacity of 5.2 mtpa. The total storage capacity of Atlantic LNG's facility is 524 000 m^3.

A feasibility study for a fifth LNG train – Train X – was completed in 2008 but there has been no further progress to date largely due to concerns about gas reserve availability.

The Government is also reviewing several proposals for new LNG projects including one based on floating LNG technology and a second that proposes a mid-scale sized project targeting the Caribbean (Algell).

Most of the LNG now produced at the terminal is committed to specific markets in the US and elsewhere but there are excess cargos sold on a spot basis, which might be used in the Caribbean LNG trade (Renwick, 2011).

In 2011 the total natural gas export in form of LNG from Trinidad and Tobago was 18.88 billion m^3 of natural gas. Its distribution to receiving continents is illustrated in the figure below.

Figure 46: *Trinidad & Tobago LNG export destinations 2011 (Billion m^3 of natural gas) (BP statistics 2012)*

4.1.17 USA

Both the United States and Canada have used natural gas for over a hundred years, in application for industry as well as commercial, and to heat residential homes (CEE, 2004).

Natural gas production in the US has not met the demand for decades; most LNG terminals in the country are import terminals. Statistics have shown continued pipeline imports from Canada, deliveries of natural gas from Alaska and an increase of LNG imports. With recent years' increasing shale gas extraction the situation has, however, changed and the need for import has decreased significantly.

Currently, there are many projects under consideration and re-evaluation for construction of onshore and offshore LNG receiving terminals in the US, some of which have received regulatory approval or are in the process of doing so. The majority, however, are awaiting regulatory approval or are about to enter the approval process. These processes control design, construction and eventual commercial viability of the new infrastructure.

Onshore facilities have been proposed in most coastal areas of the United States. However, the US Gulf Coast region is where most new onshore facilities have received approval from the Federal Energy Regulatory Commission (FERC), the responsible authority for onshore LNG import facilities. LNG import terminals have so far mostly been built on shore.

The option of developing offshore LNG import receiving and regasification capacity raises both opportunities and challenges. In some locations, an offshore receiving terminal may provide a better alternative due to the use of existing offshore facilities and pipelines, easier access for LNG tankers, and more flexibility to adapt to regulated exclusion zones. The drawbacks are distant access to natural gas distribution pipelines, lack of onshore services and in most instances, higher initial investments.

Along the US Gulf Coast, offshore LNG facilities can be developed to connect with available infrastructure, such as subsea pipeline networks, that are not used to their full capacity. The US Gulf Coast has a vast natural gas pipeline network that was built to serve shallow water exploration and production activity. Spare capacity is available in this infrastructure to carry natural gas to shore from offshore facilities. Offshore LNG facilities can also be placed to serve more than one market area and can provide convenient alternatives for LNG shipping (CEE, 2006).

Offshore LNG operations also face a different jurisdictional environment under the Deepwater Port Act (DWPA). The federal authority for the DWPA is the Maritime Administration (MARAD) with the US Coast Guard (USCG) (applicable for terminals in federal waters).

There are diverse approaches to offshore LNG receiving and regasification terminals. The LNG offshore import terminal design depends on many factors such as: the use of existing infrastructure (platforms, underwater pipelines); the constraints imposed by water depth (shallow versus deep); the need for local LNG storage facilities; and the opportunities for use of seawater to provide heat for the regasification process

LNG import facilities

There are several operating LNG import terminals in the United States today: 12 US facilities (and one facility in Puerto Rico) are capable of importing LNG of which eight are located within the WCR (CLNG, 2012):

- Elba Island, Georgia
- Lake Charles, Louisiana
- Gulf Gateway Energy Bridge, Gulf of Mexico
- Freeport, Texas
- Sabine, Louisiana
- Hackberry, Louisiana
- Sabine Pass, Texas
- Pascagoula, Mississippi

Imported LNG accounts for slightly more than 1% of natural gas used in the United States and are supplied via ocean tanker, the majority with LNG from Trinidad and Tobago, Qatar and Algeria, with some shipments from Nigeria, Oman, Australia, Indonesia and the United Arab Emirates.

According to the EIA (US Energy Information Administration), USA imported 11.6 billion m^3 natural gas (0.41 Tcf) in the form of LNG in 2010. Due to increased domestic production, LNG imports are expected to decrease by an average annual rate of 4.1%, to levels of 4 billion m^3 natural gas (0.14 Tcf) by 2035 (NaturalGas.org, 2011). By 2016 the US is also expected to be a net exporter of LNG. Increase in LNG production is primarily a result of increased shale gas production due to new technologies. EIA expects the US to export around 3 million m^3 LNG (1.1 Bcf) per day, starting 2016. The EIA has also reported that offshore natural gas in the Gulf of Mexico stood at around 6.8 billion m^3 natural gas (2.4 Tcf) per year. Shale gas reserves in the US are estimated to 15.3 trillion m^3 (542 Tcf) (EIA, 2012).

LNG export facilities

Although outside the WCR, it is worth mentioning the only dedicated export facility in the US, located in Kenai, Alaska. Owned by ConocoPhillips/Marathon, the plant exports 1.3 million tonnes per annum. LNG is being exported to Japan, and further supplies to the Asian continent are under consideration (CEC, 2010b). Natural gas is exported here because without a pipeline or an LNG import terminal on the West Coast, it is impossible to bring the Alaskan natural gas to the lower 48 states for domestic consumption. Though the Kenai Peninsula facility is the only US terminal currently exporting LNG, three of the existing LNG import facilities have been authorized to re-export delivered LNG and one has applied for authorization to do so. The three LNG import facilities authorized to re-export delivered LNG are located in:

Freeport (TX), Sabine (LA), and Hackberry (LA).

There are also a number of potential sites for new LNG terminals, both export and import (CLNG, 2012).

Existing terminal owners are also converting to LNG exports. Both Cheniere (Sabine Pass LNG) and Freeport LNG have announced plans to build liquefaction facilities to export gas from the US. The two companies built large LNG import terminals some years ago when the US was relying on gas imports and since the locations of the terminals on US Gulf of Mexico coast are very convenient for both Central America and the Caribbean, they are seen as very good candidates for LNG supply to the region in addition to the current supply from Trinidad (Suvisari, 2011).

New liquefaction trains

At Sabine Pass, Louisiana, as much as seven million tonnes a year of LNG can be exported from the Cheniere Energy LNG terminal, and it will most certainly be a competitor for the Caribbean market. Terminal owner Cheniere has signed a non-binding agreement to sell 600 000 tonnes a year of LNG to the Dominican Republic starting 2015 (Cheniere Energy, 2011), motivating the decision to build four liquefaction trains for 18 mtpa in total. Several companies have already booked large quantities at the respective trains (BG Group, Gas Natural Fenosa of Spain, Gail in India) (Martin, 2012c). These negotiations contribute to an advanced position for a final investment decision as Cheniere will have roughly 89% of its capacity tied up on long-term agreements, adding a certainty to a long-term cash flow for the project (Martin, 2012d).

Freeport LNG plans a three-train liquefaction project. Permits to site, construction and operation of the facility will be received by September 2013, allowing request of permission right after. The first train is planned to be online in the last quarter of 2016. The overall construction schedule is set to take between 48 and 54 months and the terminal will include three 4,4 mtpa trains, pipe connections, a storage tank and a permanent construction dock (Meredith, 2012d).

Texas-based Excelerate is another company with interests in the LNG export market. The company has one project in the WCR, off the Texas coast in the Gulf of Mexico, outside Port Lavaca. It will be the first offshore liquefaction facility in the US and it will be ready to export LNG worldwide by 2017, interconnected to the region's existing pipeline system to receive natural gas and liquefy it on board the vessel. The Floating Liquefaction Storage Offloading vessel (FLSO) will get a production capacity of 3 million tonnes per annum (3 mtpa), a storage capacity of 250 000 m^3 LNG, and a fully integrated gas processing plant. The 338-metre long, 62-metre wide FLSO will be permanently moored and have multiple connections to the onshore natural gas grid in South Texas and can be adapted to most applications used near shore or offshore. The Port Lavaca location has previously received FERC approval as an LNG import facility (Marino, 2012b).

Other solutions for export of LNG is Seaboard's, a US-based corporation, proposal to export LNG on shipping containers to markets in the Caribbean and Latin America. Permissions to export 550 000 tonnes per annum over 25 years to countries with a US free trade agreement are sought. Seaboard plans to ship out LNG on standardized containers that can be loaded on standard containerships. The project is targeted to start early 2014 (Martin, 2012b).

4.1.18 Venezuela

Venezuela had 5 trillion m^3 (179 Tcf) of proven natural gas reserves in 2011. PdVSA (Petróleos de Venezuela S.A.) produces the largest amount of natural gas in the country, and it is also the largest natural gas distributor, although a number of private companies also currently operate in Venezuela's gas sector.

Venezuela is working to increase the production on gas (non-associated with oil) mostly through the development of its offshore reserves. Offshore exploration has yielded several successful finds (Shepard & Ball, 2004). In September 2008, Venezuela signed initial agreements to create three joint venture companies to pursue LNG projects along the northern coast of the country. Each project will consist of a separate liquefaction train with the capacity to export LNG corresponding to approximately 2,8 trillion m^3 (101.3 Tcf) of natural gas per year (EIA, 2011). The LNG export projects are currently frozen as a result of falling gas prices. Pricing issues have meant that PDVSA has struggled to attract investment from foreign companies with the right experience. This affects the offshore Mariscal Sucre project, estimated at 416 billion m^3 (14.7 Tcf). The Gran Mariscal de Ayacucho Industrial Complex (CIGMA) is an ambitious LNG project that has mostly been on hold for almost a decade (Wallis, 2011).

5
The LNG potential for typical WCR ship segments

In chapters 2, 3 and 4 the present and future shipping activities as well as the present and future LNG availability in the WCR are described. In this chapter some typical ship types and ship segments will be evaluated in term of its suitability as early adopters for LNG as marine fuel.

In principle any ship or ship type is suitable to use LNG as fuel if LNG is available in necessary quantities in suitable positions and at a competitive price. Since this ideal situation will not be present in either a global or a WCR context for many years to come, it is clear that some ships/ship types/shipping segments are more suitable than others.

5.1 Key aspects

Evaluating the suitability of different ship types, shipping segments and even a specific ship or operations with respect to early introduction of LNG as fuel, a number of technical, operational and commercial parameters have to be considered.

5.1.1 Range requirements

Since LNG has a lower energy/volume ratio[8] than traditional FO, the space requirements for LNG are higher than for FO. In addition LNG tanks are much more complex and space consuming in relation to FO tanks since LNG have to be handled at low temperatures down to −163°C. This implies that a ship type with a significant range requirement needs relatively large tanks, which may have significant impact on cargo capacity and investment cost. A more optimized approach when it comes to range is necessary when using LNG as fuel.

A possible solution to keep LNG tank reasonably small is to use dual fuel (DF) engines as described in detail in chapter 3.

5.1.2 Suitable bunkering solutions

As per the traditional FO bunkering there are three main methods to do LNG bunkering. Each has its own characteristics and applicability.

[8] Approx. 2:1 LNG:FO.

Figure 47: *Schematic illustration of the three main methods of LNG bunkering*

Figure 48: *Truck to ship bunkering (TTS) of LNG*

Today the most common LNG bunkering method is truck to ship and it is a feasible option as long as the volumes are reasonably small. A tank truck can carry up to approximately 25 tonnes of LNG depending on the capacity of the tank truck, the national transport and vehicle regulations, the road infrastructure and the standard of the roads to be used. If the receiving vessels require large quantities (>50 tonnes) other bunker methods are more suitable.

The main benefit of TTS operation is that the initial investment is limited and that the necessary investments are possible to use also for other purposes such as local energy distribution, etc. This makes TTS bunkering a very good start up solution or LNG bunkering.

On the negative side, the limited capacity is the most obvious limitation. Depending on what ship type the bunker TTS operation may also have a significant impact of the possibilities to parallel operation such as cargo and passenger handling since the bunker operation has to be carried out on the quay side of the vessel. Another obvious limitation is that the preferred bunkering position has to be connected by road to the source of LNG.

Intermediate tank to ship (TPS)

Figure 49: *Tank to ship bunkering (Photograph reproduced courtesy of Eidesvik)*

Another commonly used bunker solution is to bunker by pipeline directly from an intermediate LNG tank. Depending on the requirements and logistical options the size of such tanks could vary from as small as a few tonnes up to larger ones at 50 000 tonnes. The LNG supply to the intermediary tank could be done by truck or ship depending on the required volumes, availability, etc. In special situations it could also be possible to use an import or export terminal as direct source for TPS bunkering.

One limitation for this solution is that it is technically and operationally challenging to have long pipelines. This implies that the tank has to be situated in the close vicinity of the berth where the bunkering operation shall be performed. To do this is not always possible since the available space in combination with safety measures and other on-going activities in the port may be limited. The solutions also have limitations when it comes to flexibility since the bunkering position is fixed. The solution is most likely to be used for a port or berth with a stable and long-term demand for bunker delivery or when a local LNG bunker demand coincides with other consumers making it possible to co-use the necessary infrastructure.

Ship to Ship (STS)

Figure 50: *Proposal for 1 400 m^3 LNG bunker vessel*

Since both TTS and TPS have clear limitations when it comes to flexibility and/or capacity, a feasible option for bunkering of LNG in the future is by ship to ship operation similar to how FO is supplied to ships today. The solution is flexible both when it comes to capacity and location, and an LNG bunker vessel can be used to bunker most kind of ship types. The main downside is that the initial investment in a bunker vessel is significant and it may be difficult to find alternative occupation in a situation when the LNG bunker demand is limited.

5.1.3 LNG availability and price

A key parameter when evaluating if a specific ship type/ship segment is suitable for LNG as fuel is availability and price.

According to both Ashworth (2012) as well as Moniz et al (2011) the most plausible development if comparing the global natural gas price with the global price of crude oil is that natural gas comes out as the favourable source of energy. The main reason for this is that the known resources of natural gas are significantly larger than crude oil and that new sources of natural gas are discovered in larger quantities than for crude.

In studying the natural gas prices over the last year there are significant regional differences with prices ranging from as low as below 3 USD/MMBtu in the US up to above 15 USD/MMBtu in Japan. The reason for this imbalance is a combination of new sources of natural gas discovered continuously especially in North America as well as peaks in demand especially in Japan related to the Fukushima nuclear accident and a capacity shortage of infrastructure for LNG production, distribution and import.

To achieve a stable and preferable low LNG price on a global level, significant infrastructure investments are necessary. At the same time LNG infrastructure is costly, which means that it is important that it is efficiently used. If not the additional infrastructural cost of LNG will be significant.

This fact is also very much relevant in a local or regional perspective and since the only price that is of any interest to a ship owner or charterer is the FOB (Free On Board price). The additional cost for necessary infrastructure to be able to deliver LNG to ships in a regional and local perspective is of great importance for the attractiveness for LNG as marine fuel.

If shipping can co-use LNG infrastructure with other consumers such as power plants, refineries, local gas grids, etc. this is an enabler for a stable supply and reasonable price. Therefore, the location of existing or planned LNG infrastructure is of significant importance when evaluating a specific shipping segment in terms of its suitability as early adapters for LNG as marine fuel.

A similar situation occurs when it is possible to induce a relatively high LNG consumption from shipping in one single bunkering spot. Then the costs for the necessary infrastructural investments may be divided between many users resulting in an attractive LNG FOB price.

5.1.4 Present and future trade area

If a vessel is predesigned to be operated on the same route or in the same area for a significant part of its commercial and/or technical lifetime it is easier to be an early adopter of LNG as fuel since a local or regional reliable availability is sufficient to make such investment plausible. This makes vessels such as ferries, RoRos, RoPaxs, more suitable to become early adopters than, for example, tankers or bulk carriers that usually are operated more globally during its lifetime. This general conclusion is invalid if a vessel of any type is designed and built for a special trade such as between two refineries or between a mine and a mill, etc.

5.1.5 Typical design limitation

Different ship types have different characteristics making them more or less suitable for using LNG as marine fuel. Some of these characteristics are also contradictory. When the development of LNG fuelled ships started in Northern Europe the focus was very much vessels operation on fixed routes or areas over relatively short distances such as ferries, RoRos, PSVs, etc. The reason for this was that the LNG tanks were much more space consuming than FO tanks, and the availability of LNG distribution networks was limited. Vessels with regular trading patterns with short periods between potential bunker occasions seem like the way to go.

At the same time the first major conversion of an existing vessel from oil to LNG as main fuel was the 25 000 dwt product tanker M/T **BIT VIKING**. This highlights the complexity of selecting which vessels are suitable to become frontrunners for the introduction of LNG as marine fuel and which are not.

Figure 51: *M/T* ***BIT VIKING*** *(Photograph reproduced courtesy of Germanicher Lloyd)*

WIDER CARIBBEAN REGION

From a technical standpoint a tanker is among the easiest ship type to convert from oil propulsion to LNG propulsion. Tankers usually have available space for tank on top of the cargo area and are well suited to handle hazardous cargos/fuel. At the same time tankers usually aren't operated on fixed routes visiting the same port on a regular basis. Therefore, a more general availability of LNG as marine fuel is necessary before the tanker segment as such is possible to use LNG as marine fuel. The reason why the Bit Viking project came through was that she got a long-term charter to be operated almost only on the Norwegian continental shelf.

The situation for container feeders is quite the opposite if compared with tankers. Container feeders are usually operated on fixed routes with regular visits to a limited number of ports. This implies that the demand for a well-developed LNG distribution system is limited and therefore makes container feeders suitable for LNG propulsion. On the other hand most container feeders have no suitable spots for the LNG tanks, which makes it more difficult to convert a container feeder from oil to LNG propulsion without losing significant cargo capacity.

5.1.6 Demand for renewal

As discussed in previous sections there are several technical and commercial challenges when converting existing vessels from FO to LNG propulsion. Typical constraints when converting any existing vessel are weight and stability, space for tanks, space for ventilation and piping ducts, non-suitable engine room layouts as well as the suitability for conversion of existing main and auxiliary engines.

These types of constraints make it much more difficult to make a conversion of an existing vessel commercially viable compared to a new building. This fact implies that if a certain shipping segment has an underlying demand for renewal of the fleet that segment has a much better potential for the introduction of LNG as marine fuel than if not. When studying a shipping segment there are several aspects that govern the underlying demand for renewal. Age of the fleet is one aspect but also other aspects such as changing quality and capacity demands from cargo owners may have a significant impact on the underlying demand.

5.1.7 Environmental consideration

In addition to the existing, planned and discussed regulatory environmental demands as described in chapter 3, the external non-regulatory demand for environmental performance varies between different shipping segments and trade areas. In general shipping segments close to public awareness and use have more external environmental demands than more cargo related shipping segments.

For shipping segments with a clear high external environmental demand it may even be a commercial necessity to be in the forefront when attracting clients and communicating with various stakeholders. Another situation when the environmental performance may be of great commercial significance is when a reduced environmental impact from shipping may be used to compensate for other related businesses with a significant environmental impact.

5.2 Tankers

As described in chapter 2, all types of tankers are operated in the WCR ranging from small product and chemical tankers up to large VLCCs (Very Large Crude Carrier). Two typical segments of interest have been selected for analysis in terms of suitability for LNG propulsion.

5.2.1 Coastal tanker

Range requirements

Coastal tankers usually visit ports regularly and therefore have rather limited range requirements between bunkering in normal operation. But since they seldom are operated on fixed routes permanently they usually tend to be designed for flexibility and with rather large bunker capacity. Based on typical range requirements coastal tankers are not very suitable for the introduction of LNG as fuel. DF-engines in combination with optimized LNG capacity and large FO capacity may be a method to reduce the problem with the range requirements.

Suitable bunkering solutions

Typical bunker consumption for coastal tankers in the WCR is approximately between 5 and 20 tonnes of LNG per day. If four days of operation between bunkering is considered as an absolute minimum for operational reasons, the smallest tankers may use TTS but for most vessels STS is the bunkering solution to use. In special cases also TPS may come in use especially if it is possible to do TPS from existing LNG infrastructure during normal operation.

LNG availability and price

Based on the typical trading patterns of coastal tankers in the WCR and the availability of existing and planned infrastructure an interesting source of LNG as fuel for this segment is the existing liquefaction plant in Port Fortin, Trinidad & Tobago. Based on a rather simple additional supply infrastructure it would be possible to deliver LNG to vessels in that area to a very attractive FOB price.

Present and future trade areas

There are few special demands on coastal tankers operated in the WCR, which means that any of these tankers may be moved to most other parts of the world if it is commercially viable. This makes it necessary to use fuels that are available globally. Therefore coastal tankers are considered less suitable for a general introduction of LNG as long as LNG is not globally available as marine fuel.

DF-engines in combination with optimized LNG capacity and large FO capacity may be a method to reduce this issue.

Typical design limitation

There are few design limitations for coastal tankers and they are among the most suitable ship types to convert from FO propulsion to LNG propulsion.

Demand for renewal

For commercial reasons the tanker segment as such has a high renewal rate since most clients have clear age limitation both for short- and long-term charters. A sample of tankers trading in the Texas City area indicated that most tankers within WCR are built after the year 2000 indicating that the fleet is rather young.

Environmental considerations

Since coastal tankers usually are operated in the coastal areas as well as visiting ports of various kinds, they are possibly more exposed to external environmental concern and requirements than other tanker types. This is extra valid for vessels that primarily are operated close to populated areas or areas with a significant tourist industry. Examples of such areas within the WCR where this could be valid are between the Leeward and Windward Islands, South of Florida and the Houston area.

Conclusion

Coastal tankers as such are not considered as suitable early adopters of LNG as marine fuel. The main reason for this is their typical trading pattern both in a short- and long-term perspective, which requires a globally available fuel. There are, however, also several parameters that make coastal tankers very suitable for LNG propulsion. This implies that it may be very suitable to use LNG as marine fuel for coastal tankers in specific trades and for specific vessels.

A typical example of such vessel/trade could be a product tanker on a long-term charter delivering refined products from the refineries in Pointe a Pierre to the Leeward and Windward Islands. Some key points that make such vessels suitable are:

– Availability to LNG in Port Fortin
– Mainly trading in an area with clear external environmental demands
– Suitable vessel type to use LNG as fuel in a technical and operational perspective
– Clients with high safety and quality standard

5.2.2 Aframax tankers

In contrast to most crude oil trades in the world the backbone of crude oil transportation within the WCR is not the VLCC. Instead most crude trade is done with Aframax tankers. The main reason for this is that few ports within the WCR and especially in the US are able to handle VLCCs.

The main route for these vessels is between a number of large Venezuelan crude export ports and US crude import ports along the Mexican gulf.

Range requirements

An Aframax tanker is traded on medium- to long-range hauls. Typical ranges between port of calls are 2 000 up to 10 000 nautical miles and they are usually designed with significant bunker capacity. A typical daily bunker consumption for an Aframax tanker is 40 tonnes LNG, which indicates a minimum requirement for LNG capacity of approximately 1 400 tonnes.

Suitable bunkering solutions

STS bunkering is the prime bunker solution based on the required volumes. In special cases also TPS may come in use especially if it is possible to do TPS from existing LNG infrastructure during normal operation.

LNG availability and price

Based on the typical trading patterns of Aframax tankers in the WCR the availability in possible bunkering ports are considered as good. Based on relatively simple additional supply infrastructure it would be possible to deliver LNG to vessels in these areas at a very attractive FOB price.

Typical design limitation

There are few design limitations for Aframax tankers and they are among the most suitable ship types to convert from FO propulsion to LNG propulsion.

Present and future trade areas

There are few special demands on Aframax tankers operated in the WCR, which means that any of these tankers may be moved to most other parts of the world if it is commercially viable. This makes it necessary to use fuels that are available globally. Therefore Aframax tankers are considered less suitable for a general introduction of LNG as long as LNG is not globally available as marine fuel. DF engines may be used to reduce this issue.

Demand for renewal

For commercial reasons the tanker segment as such has a high renewal rate since most clients have clear age limitation both for short- and long-term charters. A sample of tankers traded in the Texas City area indicated that most tankers within WCR are built after year 2000 indicating that the fleet is rather young.

Environmental considerations

Since Aframax tankers primarily are used between main industrial ports the external environmental requirements in addition to the existing rules and regulations are considered limited.

Conclusions

Aframax tankers as such are not considered as suitable early adopters of LNG as marine fuel. The main reason for this is their typical trading pattern both in a short- and long-term perspective, which requires a globally available fuel. At the same time Aframax tankers as such are easy to design or convert to LNG propulsion.

A typical example of an Aframax tanker suitable for LNG propulsion in the early stages is a crude tanker on a long-term charter delivering crude from the Venezuelan ports to the US ports along the Mexican gulf. Several existing and possible future sources of low prized LNG are available in both ends of the trading pattern.

Some key points that make such vessel suitable are:

- Clear availability of LNG in the designated trade area
- Suitable vessel type to use LNG as fuel in a technical and operational perspective
- Clients with high safety and quality standards

In a design perspective tankers in general are among the most suitable vessels to use LNG as main fuel since they usually have significant space available for LNG tanks on top of the cargo area. They also have crews that are skilled in handling dangerous cargo and they are designed with high safety standards when it comes to mitigating risk for fire and explosion, etc. The demand for renewal is high based on strict age requirements from the main customers.

On the other hand their trading pattern usually requires a globally available fuel, which makes them less suitable to become early adopters of LNG. The range requirements are also relatively high.

If any tanker/tanker trade within the WCR should become suitable for LNG propulsion in a short or midterm perspective long-term commitments between the cargo and ship owner as well as the LNG supplier is the key. If such arrangement could be realized it would be possible to create tanker operations with high environmental standards in combination with a low overall cost.

5.3 General cargo

As described in chapters 2 and 3 there is a clear trend to an increased containerization of all kinds of general cargo within the WCR. The number of communities connected directly to major transhipment ports are and will be limited and the demand of container feeders will grow. The suitability of container feeder using LNG as marine fuel is therefore interesting.

5.3.1 Container feeders

Range requirements

A typical container feeder route is between one or two weeks. A required minimum range is then approximately 3 000 nautical miles between bunkering. If the route is served by a 1 000 TEU container vessel such as the one in the figure below, it requires approximately 400 tonnes of LNG per bunkering.

Figure 52: *The 979 TEU/GT 10 851 container feeder vessel* ***TROPIC CARIB***
(Photograph reproduced courtesy of FKAB Marine Design)

Suitable bunkering solutions

STS bunkering is the prime bunker solution based on the required volumes. In special cases also TPS may come in use especially if it is possible to do TPS from existing LNG infrastructure during normal operation.

LNG availability and price

The key to secure LNG availability and price for the container feeder segment is that LNG will be made available in one or several of the large transhipment ports within the WCR. Today there is no available LNG infrastructure in any of the major transhipment ports but there are several projects planned or proposed in Panama, Jamaica and in the Florida/Bahamas region. If any of these projects become realized, the condition for the introduction of LNG as main fuel for LNG feeders will become significantly improved.

Typical design limitation

In a design perspective and in comparison with other ship types container feeders are less suitable for LNG propulsion. The main reason for this is that it is difficult to find suitable space for the LNG tanks in a traditionally designed container feeder. Therefore a conversion of existing container feeders often implies significant reduction of cargo capacity, which makes it commercially challenging.

For new buildings the situation is different and less complex but requires some innovative ideas in the design phase to fit the tanks into the design without reducing the comparative cargo capacity.

Present and future trade areas

Container feeders operated in the WCR are similar to container feeders traded elsewhere. In this perspective it is necessary to use fuels that are available globally to maintain second-hand value and reduce the commercial risk. At the same time container feeders usually are more integrated in a specific supply chain operated long-term on fixed routes or in fixed areas. This implies that it is more likely for a container feeder to be operated in one region during its lifetime if for example comparing it with equally sized product tankers. Based on this and seen in a trade area perspective, it is difficult to give a general statement of the suitability of LNG propulsion on container feeders.

Demand for renewal

Based on the on-going change of the General Cargo/Container feeder market in the WCR as well as the coming augment maximum dimensions of the Panama Canal the most likely development is that the demand for container feeder capacity in the WCR will increase. Some of this demand will be fulfilled with second-hand vessels from other markets but there will also be a clear demand for newly built vessels.

A sample of container feeders operated in the Miami area indicates that an average age of the feeder fleet is approximately 10 to 15 years old.

Environmental considerations

Since container feeders usually are operated in the coastal areas as well as visiting ports of various kinds they may be more exposed to external environmental requirements than other ship types and segments. This is extra valid for vessels that primarily are operated close to populated areas or areas with a significant tourist industry. Examples of such areas within the WCR where this could be valid are between the Leeward and Windward Islands, South of Florida and the Houston area.

Conclusion

To use LNG as the main fuel for the container feeder segment within the WCR consists both of possibilities and challenges, and it is difficult to make a general prediction with regard to suitability and early adaptation for LNG. Some factors that make the segment more interesting than others are the on-going change and consolidation of the cargo flows, which may open up significant possibilities to introduce LNG as fuel for container ships especially if combined with the increased availability of LNG infrastructure as indicated in chapter 4.

An underlying demand for new vessels in combination with a developed LNG infrastructure for LNG may open up great opportunities to introduce LNG as fuel for the container feeder segment in the WCR. To make it work, it is important to see the fuel supply chain as one important aspect to consider when designing integrated container feeder systems. Cooperation between LNG suppliers, ship owners, port authorities as well as cargo owners is necessary. The clear upside of such cooperation would be cost efficient and environmentally friendly container transportation in the area to the benefit of both the economy and the environment.

5.4 Bulk

As described in chapter 2 most of the dry bulk shipping within the WCR is related to shipments of dry-bulk commodities between the US Gulf Coast ports and ports outside the WCR. This kind of shipping will not be further discussed in this chapter.

The other type of dry bulk shipping is a more small-scale artisanal intra-regional dry bulk shipping which is very similar to the small general cargo segment. By reasons discussed in previous chapters, this segment is anticipated to decline and partly be replaced by container traffic and will not be further analysed.

5.5 Tug and supply

As described in chapter 2 there are two different dominating types of tugs used within the WCR, harbour tugs and tugs used for barge transports. Since they have totally different operational patterns, their suitability for LNG as fuel is different. Supply vessels are primarily used in the Mexican Gulf.

5.5.1 Harbour tugs

Harbour tugs are used in all major ports within the WCR. Their prime occupation is to assist vessels entering or leaving ports but they may also be used for towing, push barge operations, emergency response operations, etc.

Range requirements

For normal operation harbour tugs have very limited range requirements between bunkering since they usually return to the home port daily. But since they usually are designed for other applications they need to withstand longer range assignments. With a daily consumption in the range of 6 to 10 tonnes of LNG, a suitable LNG bunker capacity could be 20 to 30 tonnes if using dual fuel machinery. If using pure gas engine the capacity increases significantly depending on the range requirements. Then the bunker capacity may be in the range of 60 to 140 tonnes of LNG.

Suitable bunkering solutions

The most suitable bunker solutions for Harbour tugs are TTS or TPS. Especially when operated from a dedicated tug port, TPS could be very suitable since several units may use the same bunkering infrastructure. A TPS solution in a dedicated tug port is very similar to what has been used for several years in the Norwegian market for supply vessels.

LNG availability and price

Since the required volumes are relatively small it is possible to supply them with trucks independently if TTS or TPS bunkering solutions are used. As long as the desired bunker position is connected by road to any main LNG infrastructure and the range is reasonably short, the additional price of the LNG will be limited. If not, a more complex supply chain is necessary, which will increase the additional price.

Typical design limitation

The main challenge when designing an LNG fuel harbour tug is to find suitable space for the tanks. Therefore it is very difficult, if not impossible to convert existing harbour tugs to use LNG as main fuel. For new builds this is different since the tanks then may be included in the original design. Still, the available space is limited and as stated above, dual fuel-propulsion is probably necessary if ranges above a few days between bunkering are necessary.

Present and future trade areas

Harbour tugs operated in the WCR are similar to harbour tugs operated elsewhere but since the necessary supply chain is rather simple through the possibility of TTS and TPS bunkering the possibility to create a supply system on a new location is considered. Since a dual fuel solution is considered as the most suitable solution based on the typical range requirements this also limits the impact of the possible problems with availability of LNG in new trade areas.

Demand for renewal

A sample of tugs operated in the St Thomas area indicates that an average age of the tug fleet is high with the bulk of the fleet built during the 1970s. This indicates a high demand for renewal that opens up possibilities to introduce LNG as marine fuel.

Environmental considerations

Since harbour tugs have their main operational area in the ports the environmental consideration and external environmental requirements may be significant depending on the specific port and its surroundings.

Conclusion

To use LNG as main fuel for harbour tugs is considered very suitable for newly built tugs operated in ports connected by road to any major LNG infrastructure. The additional price related to the required LNG infrastructure is considered limited, especially if there is a strong external environmental concern from people and activities adjacent to the operational area: there may be several commercial and PR related advantages to go for LNG. On the other hand if there is no available LNG infrastructure in the vicinity, the introduction of LNG as marine fuel within the harbour tug segment is less likely.

Figure 53: *Typical tug boat*

5.5.2 ATB/ITB/push barges

As stated in chapter 2 push barge solutions in general and ATB/ITB solutions in particular are commonly used in several areas within the WCR.

Range requirements

In relation to harbour tugs the tugs used for ATB/ITB solutions usually have significantly larger range requirements. With a daily fuel consumption of approx. 10 to 30 tonnes of LNG this a normal required bunker capacity of between 50 to 250 tonnes of LNG. With dual fuel machinery it may be possible to optimize the LNG capacity to a specific range requirement but independently a significant amount of LNG is required.

Suitable bunkering solutions

Based on the required volumes, ATB/ITB operations require bunkering solutions by TPS or STS since the capacity of TTS may be too limited.

LNG availability and price

The main operation areas for the ATB/ITB vessels within the WCR are along the US Gulf Coast, an area with a well-developed LNG infrastructure. In this area it will be rather simple and cost efficient to make LNG available as marine fuel at a competitive price.

In the northern Leeward Islands the situation is different since the LNG infrastructure availability is not as developed there. Additional infrastructure is necessary and the present lack of infrastructure reduces the potential of early adoption of LNG as marine fuel in that area.

Typical design limitation

The main challenge when designing an LNG ATB/ITB tug is to find suitable space for the tanks. Therefore it is very difficult, if not impossible, to convert existing tugs to use LNG as main fuel.

A possible solution that needs to be further evaluated is to store the main part of the LNG supply on the barge. This would be especially suitable for barges designed for oil products and chemicals.

For newbuildings this is different since the tanks then may be included in the original design. Still the available space is limited and as stated above dual fuel propulsion is probably necessary to be able to optimize the LNG capacity based on a certain range.

Present and future trade areas

ATB/ITB operation is not a global phenomenon and these types of vessels are primarily used in US waters and waters adjacent to US waters. This fact reduces the demand to use a globally available fuel.

Demand for renewal

A sample of tugs operated in the St Thomas area indicates that an average age of the tug fleet is high with the bulk of the fleet built during the 1970s. This indicates a high demand for renewal that opens up possibilities to introduce LNG as marine fuel.

Environmental considerations

Since ATB/ITB usually are operated in the coastal areas as well as visiting ports of various kinds they are more exposed to external environmental requirements than other ship types and segments. This is particularly valid for vessels that primarily are operated close to populated areas or areas with a significant tourist industry. Several of the main trade areas for these kinds of vessels are of this kind.

Conclusion

The main challenge if introducing LNG as fuel for ATB/ITBs is how to fit large enough tanks to fulfil the range requirements. For tug newbuildings used for ATB/ITB operation it will be possible but for the existing fleet it is almost impossible. One potential solution to solve this would be to put some of the fuel capacity on board the barge but that implies that additional safety precautions need to be addressed and new risk reduction measures developed. If the range requirement is disregarded, this type of shipping is suitable since there already is a well-developed LNG infrastructure available in its main area of operation.

5.5.3 Offshore supply vessels

The main areas of operation of offshore supply vessels are in the Mexican Gulf along the US Gulf Coast.

Range requirements

An offshore supply vessel usually is operated for 14 days between port of calls with a fuel requirement of approximately 100 to 200 tonnes of LNG but the fuel consumption may vary considerably based on the specific task. Dual fuel machinery will increase the range flexibility

Suitable bunkering solutions

Based on the required bunkering volumes for PSVs, TPS or STS bunkering solutions may be feasible. There are, however, few strict demands on short turnaround times in port and TTS bunkering with several trucks per bunkering occasion may also be possible. Since PSVs often are operated out of specific base ports a TPS solution may be the most suitable and cost efficient especially if several LNG fuel vessels are operated out of the same base port.

LNG availability and price

The main operation areas for the offshore supply vessels are in the Mexican Gulf and especially along the US Gulf Coast, which is an area with a well-developed LNG infrastructure. In this area it will be rather simple and cost efficient to make LNG available as marine fuel at a competitive price.

Typical design limitation

The space availability for the fuel tanks may vary depending on type and design of the offshore supply vessel. It is therefore difficult to make a general assumption on the possibility to convert PSVs to LNG propulsion. PSV newbuildings are considered suitable for LNG propulsion.

Present and future trade areas

PSVs operate globally wherever offshore oil and gas supplies shall be explored but since LNG production often is available in the vicinity of this operation the problem with present and future trading areas is considered limited.

Demand for renewal

With an increasing interest in deep-sea offshore oil and gas reserves there is a plausible demand for new and more complex PSVs within the WCR.

Environmental considerations

Oil and gas exploration and production is usually under stringent external pressure to improve its environmental performance. At the same time it is difficult to make significant changes to the environmental performance of the business as such. Therefore PSVs may be extra suitable for the introduction of LNG since it could be a rather simple way to improve the overall environmental preference of the business. This development is also seen on the Norwegian continental shelf.

Conclusion

PSVs within the WCR are considered one of the most suitable segments for the introduction of LNG. In the main areas of operation the availability of LNG is good and there is a potential for significant demand for new vessels.

Figure 54: *Typical offshore supply vessel*

5.6 Passenger vessels

5.6.1 Cruise

Forty per cent of the world's total cruise capacity is operated in the area between Florida, the Bahamas and the Northern Leeward Islands. Most of these vessels are on seven day cruises using one of the main cruise ports in southern Florida as a base port.

Range requirements

A typical cruise ship has a daily consumption in the range of 100 to 150 tonnes of LNG. For a seven day trip the consumption is approximately 1 000 tonnes of LNG. If combined with dual fuel propulsion a fuel capacity of only seven days is sufficient as long as it is possible to increase the range with FO when moving for occasions when longer range is required.

Suitable bunkering solutions

Based on the required volumes and characteristics STS bunkering is the main bunkering solution for cruise vessels.

LNG availability and price

At present there is no available LNG infrastructure in the vicinity of the main base ports for the cruise industry on southern Florida but a number of projects are under development. If any of this will be realized the additional price for a supply system will be rather limited.

With a major change of main fuel with the cruise industry the potential volumes are of such magnitude that the cruise industry itself may be able to cover the full cost of a dedicated supply system including a regional LNG terminal.

Typical design limitation

To convert existing cruise vessels is challenging since the available space for LNG tanks is limited without losing too much valuable space. For new builds the situation is rather straightforward. The main concern may be the perceived risk of LNG among the consumers but with the vast number of LNG as marine fuel related projects on-going in other North American areas concerning passenger vessels of various kinds, this perceived risk among the consumers will probably sag during the year to come.

Present and future trade areas

A cruise vessel is likely to be operated on various areas during its lifetime and may also change trade areas for seasonal reasons. Therefore a globally available fuel may be necessary for cruise vessels.

Demand for renewal

The cruise industry thrives on new, bigger and better vessels and the renewal of the fleet is continuous for commercial reasons.

Environmental considerations

The cruise industry as such has very high external environmental requirements. Since there is public awareness of how passengers' consumption affects the environment, it is important for the cruise industry to appear to be a responsible industry in terms of environmental performance. A similar situation is valid in relation to the ports and communities visited by these vessels since the emissions from the cruise vessels may have a negative impact both on local environment, health and the competitiveness of the local tourist industry.

Conclusion

Newbuildings of cruise vessels dedicated to operate out from the cruise ports of southern Florida are among the most suitable vessels for LNG propulsion among all vessels types operated in the WCR since it combines excellent environmental performance with a potential for fuel cost. The main negative aspects to consider are a limited commercial flexibility in terms of trade area and range as well as the present lack of the necessary LNG infrastructure in the vicinity of the main base ports.

5.6.2 Small ferries

Smaller passenger ferries, RoPax vessels and high-speed vessels, etc. are operated in many areas of the WCR. Since the characteristics of these vessels vary it is difficult to make any detailed conclusion but some general considerations may be pointed out.

Range requirements

Usually these types of vessels have rather limited range requirements since they usually only trade short distances between island communities, etc. and on regular time schedules.

Suitable bunkering solutions

All types of bunkering solutions may be suitable depending on bunker volume requirements, bunkering times and bunkering position.

LNG availability and price

If LNG may be sourced from existing LNG infrastructure in the vicinity of the normal area of operation a reasonable price is possible; if not it is more difficult to create a cost efficient supply system.

Typical design limitation

In general it is difficult to convert vessels in this segment but for new buildings there are few design limitations to consider.

Present and future trade areas

Vessels in this segment are usually operated more long term on specific routes than most other segments. This makes them more suitable to dedicated bunker solutions.

Demand for renewal

Usually the vessels in these segments have a long technical lifetime if well maintained. Instead it is usually changing commercial terms that induced investment requirements for new vessels. Therefore it is difficult to make any general assumptions since it very much differs from case to case.

Environmental considerations

Depending on where the vessels are operated, the external environmental requirements may vary but in general the environmental performance of the vessels in this segment is important since they usually are operated close to populated areas.

Conclusion

It is difficult to make a general statement for this segment since its circumstance varies on a case-by-case basis. A number of aspects are important, such as demand for renewal, a long-term perspective, as well as available reasonable prices of LNG, and must be carefully considered to determine whether a specific service is suitable or not for introducing LNG as marine fuel. At a workshop within this project, the specific ferry service between the Trinidad and Tobago islands was identified as an example of an interesting potential pilot route for LNG adoption. LNG is available, the potential operational savings are high and the operator is planning for long-term renewal of its ferry fleet.

5.7 Overall conclusion and comparison

In this chapter a number of identified technical, operational and commercial key aspects of LNG feasibility have been assessed for various ship segments operating in the WCR. Some of the segments are considered more suitable and likely to become early adopters than others but for all of them there are both favourable and less favourable aspects identified and the segments show different profiles with respect to suitability for introduction of LNG as fuel.

The respective profiles are summarized in the table below in which an indicative ranking of the relative suitability for the different studied WCR shipping segments is outlined.

Table 9 – *Ranking of overall suitability for LNG adaptation of different ship segments*
1 indicates high suitability, 2 medium and 3 less suitability

Ship type segment	Typical bunker volume (tonnes)	Suitable bunker solution	Estimated additional distribution cost	Trade area require-ments	Possibilities for conversion	Demand for renewal	External Environ-mental demand	Overall suitability ranking
Coastal tankers	20–200	STS	2	3	1	2	2	2
Aframax tankers	1 400	STS	1	3	1	2	3	2
Container feeder	400	STS	2	2	3	1	2	2
Harbour tugs	20–30	TTS/TPS	2	2	3	1	1	2
ATB/ITB	50–250	STS/TPS	3	1	3	2	2	3
PSV	100–200	TPS	1	1	2	1	1	1
Cruise	1 000–1 500	STS	1	2	3	1	1	1
Smaller ferries	5–500	TTS/STS/TPS	3	1	3	2	1	2

6
Analysis

6.1 Approach for estimation of the future LNG demand

A number of factors will influence and determine the future demand for LNG as ship fuel in the WCR. The different shipping segments will show different rates of adaptation for LNG operation based on careful comparative assessment of the long- and short-term operational economy. Predictions of the LNG adoption rate figures can be made with guidance from the descriptions in chapter 5 but are also a function of time. The demand is assumed to grow gradually over time and stepwise at the point at the dates when new stringent emission limits become effective.

In the table in section 5.7, an indicative overall suitability ranking for LNG adaptation is suggested in three levels from 1–3 where 3 indicates the highest suitability. From the development scenarios of future ECA regulations in the WCR outlined in section 3.4 it is reasonable to assume that high suitability ranked ship segments will be among the earliest adopters and show a relatively high adoption rate (fleet fraction adopting LNG as the main fuel) over time compared with segments with lower suitability ranking.

In order to estimate future LNG bunker demand for a specific segment, an average daily fuel consumption per vessel, average hours per day in operation and the number of vessels in service multiplied by an assumed adoption rate would result in an estimated LNG fuel consumption or demand for a particular ship segment engaged in a specific route service at a specific time of development scenario.

The REMPEITC database covers all ship movements including departure and destination ports defining each route. The most frequently trafficked routes were listed for each segment in the top-20 lists, but complete lists including also all low frequency trafficked routes would be very long. Distances travelled or time spent for each of the routes is unfortunately not included in the database and therefore it was not practically feasible to calculate the accumulated distances and fuel consumption for each ship segment in this study.

A number of examples for specific segments and services may, however, illustrate the described approach and give a quantitative indication on potential future increasing demand for LNG as ship fuel.

6.1.1 Cruising segment

According to the route analysis in chapter 2 and the use of REMPEITC map application the following cruising route scenario is considered representative.

Scope	Large cruising vessels engaged in 7-day cruises between turnaround ports in SE Florida and the Puerto Rico area
Typical ship size	50 000 GT
FOC	150 tonnes/day. Operating on average 16 h/day @ 20 knots is 100 tonnes/day
Route	Total travelled distance 2 000 nautical miles per route
Number of vessels	Total of 25 vessels in this ship and size segment engaged in this and similar services in the area
LNG adoption	LNG adoption rate assumed to be 5% by 2015 LNG adoption rate assumed to be 20% by 2025
LNG demand	875 tonnes LNG/week 2015, 3 500 tonnes/week 2025 44 500 tonnes LNG/year 2015, 182 000 tonnes/year 2025

6.1.2 Container feeders

According to the route analysis in chapter 2 and the use of REMPEITC map application, the following container feeder route scenario is considered representative for the Jamaica – Trinidad area.

Scope	Container feeder engaged in 7-day routes between Kingston Jamaica, Grenada and Trinidad area
Typical ship size	10 000 GT, 900 TEU
FOC	50 tonnes/day. Operating on average 12 h/day @ 18 knots is 25 tonnes/day
Route	Total travelled distance 3 000 nautical miles per route
Number of vessels	Total of 10 vessels in this ship and size segment engaged in this and similar services in the area
LNG adoption	LNG adoption rate assumed to be 10% by 2015 LNG adoption rate assumed to be 30% by 2025
LNG demand	8 700 tonnes LNG/year 2015, 26 000 tonnes/year 2025

6.1.3 ATB/ITB tug

According to the route analysis in chapter 2 and the use of REMPEITC map application, the following ATB/ITB tug services scenario is considered representative for US Gulf Coast area.

Scope	ATB/ITB tug engaged in coastal operation between ports along the US Gulf Coast within the North American ECA
Typical ship size	500 GT
FOC	20 tonnes/day. Operating on average 18 h/day is 15 tonnes/day
Route	Total travelled distance 200 nautical miles per day
Number of vessels	Total of 50 vessels in this ship and size segment engaged in this and similar services in the area
LNG adoption	LNG adoption rate assumed to be 20% by 2015 LNG adoption rate assumed to be 50% by 2025
LNG demand	8 700 tonnes LNG/year 2015, 26 000 tonnes/year 2025

6.1.4 Crude carrier

According to the route analysis in chapter 2 and the use of REMPEITC map application, the following crude carrier services scenario is considered representative for the US import from Venezuela.

Scope	Crude carrier engaged in 14-days routes between the Houston area and Puerto José, Venezuela
Typical ship size	Aframax 100 000 dwt
FOC	40 tonnes/day. Operating on average 20 h/day @ 14 knots is 33 tonnes/day
Route	Total travelled distance 4 000 nautical miles per route
Number of vessels	Total of 5 vessels in this ship and size segment engaged in this and similar services in the area
LNG adoption	LNG adoption rate assumed to be 20% by 2015 LNG adoption rate assumed to be 40% by 2025
LNG demand	12 000 tonnes LNG/year 2015, 23 000 tonnes/year 2025

From the above examples and taking into account that the presented segment services only represents a very small portion of the total WCR internal traffic, it is obvious that the LNG demand for ship fuel may increase rapidly if the LNG adoption rate will get high. The examples also indicate that segments with large ships and high fuel consumption may represent a large portion of the LNG demand even though the LNG adoption rate in the segment is low.

Given that the assumed LNG adaptation rate also corresponds to an MGO adoption rate and an HFO plus scrubber adoption rate with a sum of 1 (100%), the described approach can of course also be used to calculate corresponding MGO and HFO demand for the analysed scenarios.

6.2 LNG infrastructure for supply of LNG for LNG fuelled vessels in the WCR

As indicated in chapter 5 one of the key enablers for the introduction of LNG as marine fuel is the ability to create a cost efficient and reliable supply chain from available sources of LNG to the LNG fuelled vessels.

As indicated in the map in chapter 4, LNG is or will be available in the near future in most areas of the WCR based on demands not related to LNG as marine fuel. This must be considered as a valuable key enabler to make WCR suitable as such for the introduction of LNG as marine fuel. It is assumed that the basic price of LNG in these non-shipping related systems are attractive based on the available regional price indications such as the Henry Hub, etc.

At the same time the LNG price in these systems is irrelevant for the shipping industry. The only interesting price for the shipping industry is the FOB price and if the FOB price is not attractive in relation to the alternatives, LNG will not be the fuel of the future in the WCR.

In principle the difference between the LNG price in the non-shipping related LNG systems and the FOB price is the cost of the required additional infrastructure to create the necessary supply systems. The key to create cost efficient supply systems is to create systems with high LNG throughput in relation to the necessary investments in every part of the supply chain.

The following four examples demonstrate how the necessary additional supply systems could be created for three different types of shipping segments.

For each example a corresponding FOB price for IFO380 is calculated based on the following figures, to allow for direct comparison with actual IFO380 price:

HUB Price LNG	4 USD/MMBTU = 190 USD/ton
Net Calorific Value LNG	13.7 MWh/tonnes
Net Calorific Value IFO380	11.3 MWh/tonnes
Net Calorific Value MGO	12 MWh/tonnes

6.2.1 The WCR cruise industry

As identified in earlier chapters, the cruise industry of the WCR has several characteristics that make it suitable for the introduction of LNG as marine fuel. The main bunkering area is considered to be the cruise ports of south-eastern Florida. At present there is no existing LNG infrastructure available in that area but there are two proposed projects in the Bahamas that if realized could be used as main sourcing infrastructure to the cruise industry. Otherwise it is probably necessary to invest in an intermediate LNG terminal in the southern Florida area.

To exemplify, the following assumption is made:

Number of LNG fuel cruise vessels	10
Required bunkering volume	910 tonnes
Required bunkering interval	7 days
Bunkering position	Port Everglades
Bunkering method	STS

Two different supply chains are evaluated, one with an intermediate terminal in vicinity of the selected bunkering position and one using one of the proposed Bahamas regasification terminals as the main source.

Cruise supply chain 1

The following figure describes the main part of supply chain one.

LNG source

Potential LNG source for this supply system is the Houston area, Savannah or Trinidad. Since Trinidad is already operative as an export terminal this is selected as the main source for this supply chain. In principle the selection of Trinidad as LNG source implies that the necessary additional infrastructure at the LNG source is limited.

LNG feeder vessel

The distance between Trinidad and Port Everglades is about 1 600 nautical miles and a return trip including cargo operation takes about 12 days. This implies that the feeder vessel has to be in the range of 20 000 tonnes.

The daily cost for a vessel with a LNG capacity of 20 000 tonnes including fuel is about 85 000 USD/day.

LNG intermediate terminal

The required size of the intermediate terminal in the vicinity of Port Everglades is estimated to 20 000 tonnes. The daily cost including both CAPEX and OPEX cost is estimated to 40 000 USD/day.

LNG Bunker vessel

For this case it is assumed that a bunker vessel with a capacity of 1 250 tonnes is required. The daily cost for such vessel including bunkers is estimated to 25 000 USD/day.

The additional price estimate for supply chain 1

In the table below the additional cost per tonne for the supply chain 1 is calculated based on the fact that all components of the supply chain are dedicated to the supply of LNG to the 10 cruise vessels in this case.

Additional cost at LNG source	0 USD/day
Cost for feeder vessel	85 000 USD/day
Cost for intermediate terminal	40 000 USD/day
Cost for bunker vessel	25 000 USD/day
Throughput per day	1 300 tonnes
Estimated HUB price LNG	190 USD/tonnes
Supply chain cost	115 USD/tonnes
Estimated FOB Price LNG	305 USD/tonnes
Corresponding FOB price IFO380	252 USD/tonnes

Cruise supply chain 2

The following figure describes the main part of supply chain 2.

LNG source

Potential LNG source for this supply system is the planned LNG regasification terminals at the Grand Bahama Island. Some additional infrastructure is required to make export of LNG possible at these terminals. The daily cost of this additional infrastructure is estimated to 10 000 USD/day.

LNG Bunker vessel

The distance between the Grand Bahama Island and Port Everglades is about 85 nautical miles and a return trip including cargo operation takes about 24 hours. To be able to supply the 10 cruise vessels in this example it is assumed that there is time to do one trip to the LNG source per week implying the capacity of the Bunker vessel needs to be in the range of 10 000 tonnes.

The daily cost for a vessel with a LNG capacity of 10 000 tonnes including fuel is estimated to 55 000 USD/day.

The additional price estimate for supply chain 2

In the table below the additional cost per tonne for the supply chain 2 is calculated based on the fact that all components of the supply chain are dedicated to the supply of LNG to the 10 cruise vessels of this case.

Additional cost at LNG source	10 000 USD/day
Cost for feeder vessel	0 USD/day
Cost for intermediate terminal	0 USD/day
Cost for bunker vessel	55 000 USD/day
Throughput per day	1 300 tonnes
Estimated HUB price LNG	190 USD/tonnes
Supply chain cost	50 USD/tonnes
Estimated FOB Price LNG	240 USD/tonnes
Corresponding FOB price IFO380	198 USD/tonnes

6.2.2 The St Thomas tug industry

As identified in earlier chapters there are a lot of different types of tugs operated in the St Thomas area. The most plausible bunkering solutions for tugs are supplied either by TTS or TPS.

At present there is no existing LNG infrastructure available on St Thomas but there is an existing regasification terminal at Puerto Rico.

To exemplify, the following assumption is made:

Number of LNG fuel tugs	10
Required bunkering volume	20 tonnes
Required bunkering interval	3 days
Bunkering position	St Thomas
Bunkering method	TPS

The following figure describes the main part of a suggested supply chain of these tugs.

LNG source

The Puerto Rice regasification terminal is selected as the source for this supply chain. Some additional infrastructure is required to make export of LNG possible at these terminals. The daily cost of this additional infrastructure is estimated to 10 000 USD/day.

LNG feeder vessel

The distance between the Puerto Rico LNG regasification terminal and St Thomas is about 100 nautical miles and a return trip including cargo operation takes about 24 hours. Considering one trip per week the feeder vessels have to have a capacity of approximately 500 tonnes.

The daily cost for a vessel with an LNG capacity of 500 tonnes including fuel is about 20 000 USD/day. Note that the usage rate of the vessel in this case is only about 15%.

LNG intermediate terminal

The required size of the intermediate terminal including bunker station for tugs in St Thomas is estimated to 700 tonnes. The daily cost including both CAPEX and OPEX cost is estimated to 12 000 USD/day.

The additional price estimate for supply chain 1

In the table below the additional cost per tonne for the supply chain 1 is calculated based on the fact that all components of the supply chain are dedicated to the supply of LNG to the 10 tugs in this case.

Additional cost at LNG source	10 000 USD/day
Cost for feeder vessel	20 000 USD/day
Cost for intermediate terminal	12 000 USD/day
Cost for bunker vessel	0 USD/day
Throughput per day	67 tonnes
Estimated HUB price LNG	190 USD/tonnes
Supply chain cost	630 USD/tonnes
Estimated FOB Price LNG	820 USD/tonnes
Corresponding FOB price IFO380	676 USD/tonnes
Corresponding FOB price MGO	718 USD/tonnes

Compared to the additional cost per tonne LNG for the cruise vessel supply chain the cost for the tug supply chain per tonne is significantly higher. The main reason for this is that the average usage rate of each component in the supply chain is low and to reduce the additional price it is necessary to co-use the required infrastructure with other users such as other shipping segments, energy production, etc.

Compared to HFO the LNG solution may be considered as more expensive but compared to MGO, which usually are used by this kind of vessel, the LNG price still is to be considered as competitive based on this example.

6.2.3 The crude tanker industry

As described in an earlier chapter there is a continuous flow of crude oil shipped on Aframax tankers from the Puerto La Cruz area in Venezuela to the port in the Houston area.

To exemplify, the following assumption is made:

Number of Aframax tankers	4
Required bunkering volume	600 tonnes
Required bunkering interval	15 days
Bunkering position	Puerto Jose
Bunkering method	STS

The following figure describes the main part of supply chain 2.

LNG source

The selected LNG source for this supply system is Trinidad. Since Trinidad is already operative as an export terminal this is selected as the main source for this supply chain. In principle the selection of Trinidad as LNG source implies that the necessary additional infrastructure at the LNG source is limited.

LNG Bunker vessel

The distance between Trinidad and Puerto Jose is about 250 nautical miles and a return trip including cargo operation takes about 48 hours. To be able to supply the one Aframax tanker per trip the bunker vessel needs to be in the range of 800 tonnes.

The daily cost for a vessel with an LNG capacity of 800 tonnes including fuel is estimated to 26 000 USD/day.

The additional price estimate per tonne LNG

In the table below the additional cost per tonne for the supply chain is calculated based on the fact that all components of the supply chain are dedicated to the supply of LNG to the four Aframax tankers used in this case.

Additional cost at LNG source	0 USD/day
Cost for feeder vessel	0 USD/day
Cost for intermediate terminal	0 USD/day
Cost for bunker vessel	30 000 USD/day
Throughput per day	160 tonnes
Estimated HUB price LNG	190 USD/tonnes
Supply chain cost	188 USD/tonnes
Estimated FOB price LNG	378 USD/tonnes
Corresponding FOB price IFO380	311 USD/tonnes

6.3 Potential barriers for LNG as ship fuel in the WCR

A number of various potential barriers for an introduction of LNG as a fuel for coastal and short sea shipping in the WCR are identified. These potential holdback aspects are related to safety issues, economy, infrastructure development, technical development and security.

6.3.1 Safety issues

LNG is a new and unknown fuel for most seafarers and port officers and it has completely different properties compared with traditional bunker fuel oil. It is well known to everyone that spillages or uncontrolled outflow of fuel oil may cause spectacular contamination and significant impact in the marine environment but spills do not usually impose severe hazards to human lives. For the use of LNG as ship fuel, the situation is contrary – an LNG outflow will evaporate and dissipate without any local environmental impact but if a cloud of vaporized LNG is ignited, fire and heat radiation will threaten human lives.

If incidents or a serious accident would occur at an early stage of the introduction of LNG as ship fuel, this could constitute a serious barrier for further development and expansion of the use of LNG as ship fuel. Therefore it is of utmost importance that stringent safety standards and regulations are developed and implemented for LNG bunkering and for the operation of LNG fuelled vessels. Excellent safety records from many years of large-scale LNG carrier operations demonstrate that it is possible to control LNG hazards efficiently by adequate design, stringent regulations and competent personnel.

Gaps and adaptation of technical regulation and standards

The international trading with LNG by the use of large LNG carriers is a shipping segment with excellent safety records. In risk terms, it shows a very low accident frequency but the potential consequences of a large-scale accident are severe. A lot of the safety experience gained from the operation LNG carriers may be adopted for the use of LNG as ship fuel but incidents and accidents may become more frequent as the number of LNG bunkering operations will be very high compared with LNG carrier loading/unloading operations. The probability for incidents will thus increase but on the other hand, the potential consequences of minor bunker related LNG discharges will be less severe than those caused by LNG carrier accidents.

The table below gives some indicative size relations between large-scale export/import operations and small- and medium-scale LNG distribution and bunkering operations.

Table 10 – *Indicative size comparison of large, medium and small scale LNG operations*

Typical characteristics	Large scale export/ import operations	Medium size feeder/ distribution operations	Small scale operations and LNG bunkering
Ship size LNG capacity, m^3	LNG carriers 100 000–270 000	LNG feeder vessels 10 000–100 000	Bunker vessels 1 000–10 000 Bunker barges 200–500
Loading pipes diameter	$\geq$ 16 inches	8–15 inches	2–7 inches

The operation of LNG carriers and handling of LNG as cargo are well regulated by the IGC Code, ISO 28460:2010 Standard, SIGTTO LNG ship-to-ship guidelines, etc. and some of these requirements may also be applied for bunkering applications. There are, however, also a number of requirements that need to be "down scaled" with regard to the quantities of LNG handled and size of the bunker vessels involved and a gap is also identified regarding detailed standards and regulations on ship-to-ship bunkering operations. Development of the IGF Code and current work conducted within the ISO TC 67/WG 10 will hopefully establish clear-cut standard procedures and equipment requirements. The process of establishment of standards and regulations may take time and interim guidelines may be developed and applied from the start. Lack of international standards or application of different standards in different WCR countries may otherwise imply technical barriers for example regarding hose connections, ESD systems and ERS.

Training and education requirements

In order to avoid barriers and minimize accident risks it is just as important as regulating technical standards for LNG bunkering, to address issues on training, education and awareness among all officers, crew members and land-based staff involved in LNG bunkering. Some of the WCR countries are developing countries where the standard of seafarers and port officers has not yet reached the level of international quality shipping. Eight of the WCR flag states were listed on the grey or black lists of Paris MoU in 2011.

Training requirements for bunker vessel operators should be comparable to those for LNG carrier crew, though it may temporarily be difficult to fulfil required time at sea experience, if a fleet of bunker vessels will be put in service over a short time. For crew in LNG fuelled vessels and for staff in land-based LNG bunkering facilities, adequate and harmonized training requirements should be established in consensus between international maritime regulators and national competent authorities regulating land-based LNG activities in ports and for road transportation.

LNG specific hazards

Of the following identified LNG specific potential outcomes of an accidental release of LNG, fire scenarios are found to be the ones governing for necessary risk control measures including determination of safety distances and site selection for bunkering facilities and operations;

- Cryogenic damage – metal embrittlement, cracking, structural failure;
- Cryogenic injuries – frost burns;
- Asphyxiation – if the air oxygen is replaced methane asphyxiation may occur;
- Reduced visibility due to unignited vapour clouds;
- Thermal radiation from various fire scenarios:
  - delayed or immediate ignition of vapour clouds (flash fire)
  - slow fire front
  - delayed or immediate ignition of vapour-air mixture (fire ball)
  - rapid burn
  - LNG pool fires or
  - flame jets from leaks in pipes, hoses, tanks or pressure vessels

- Rapid phase transition, RPT;
- Vapour cloud explosion (in confined spaces and enriched with other hydrocarbons);
- Boiling liquid expanding explosions (BLEVE);
- Rollover in LNG storage tanks;
- Sloshing in onboard LNG tanks;
- Geysering – expulsion of LNG from a quiescent liquid in piping.

The figure below illustrates the formation of an LNG pool and vapour cloud for a large-scale spill.

The flammability range for vaporized LNG (methane) in air is relatively narrow, 5% (LFL) to 15% (UFL) compared with many other flammable gases, but if ignited the emissive power from methane is higher than for example for propane. Methane is, in contrast to propane, lighter than air and vaporized LNG from small leakages will therefore dissipate relatively quickly. For a large LNG spill, the visible white cloud of cold vaporized LNG will, however, initially have neutral buoyancy in air.

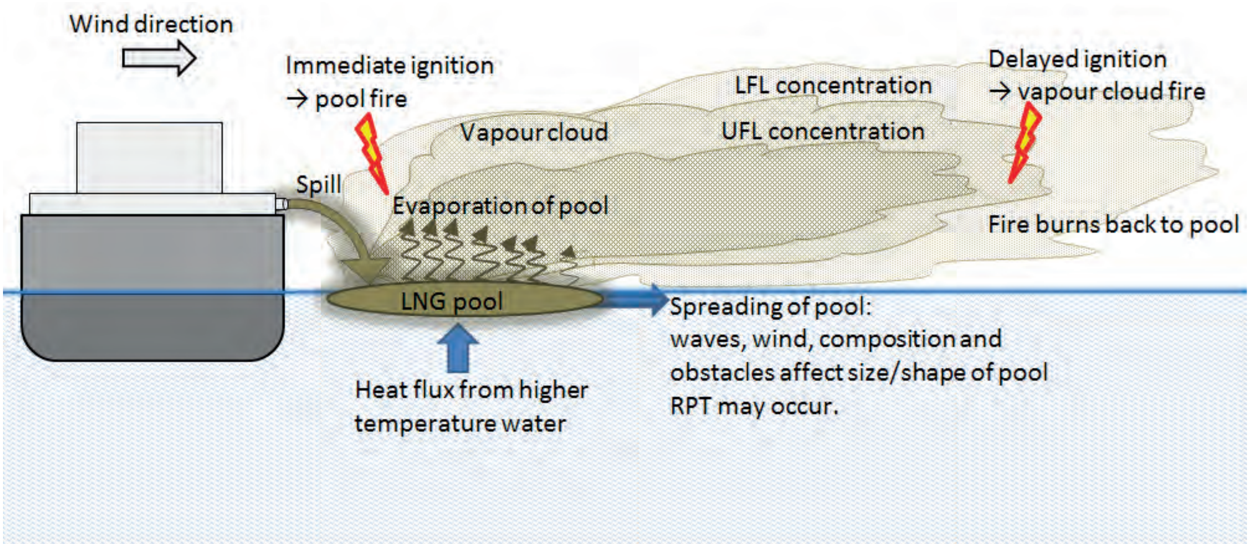

Figure 55: *Possible outcome of LNG spill over water*
Source: SSPA (Based on Luketa-Hanlin, 2006)

6.3.2 Economy related issues

A number of different potential barriers are related to the investments and operational costs for adaptation to LNG and the cost relation compared with other optional compliance strategies. The investment costs for LNG may be predicted accurately but the long-term price predictability of the LNG may be considered as a parameter of uncertainty.

The present Henry Hub LNG price of relevance for the WCR is low compared with other market regions and there are no indications identified that this situation will alter dramatically in the near future.

The increasing production of shale gas in the USA reduces the risk for lack of supply of LNG even with a continued increase of LNG consumption in the WCR. The main demand for LNG will most likely continue to be from land-based industrial users and distribution networks and even with a quick maritime LNG fuel expansion the risk for lack of supply and increasing prices are low.

Also with possible future increased export of LNG from the USA, it is not anticipated that LNG prices will increase dramatically in the WCR (Medlock, 2012).

Taxation of maritime fuels are generally harmonized in order to avoid negative competitive factors. Possible introduction of national taxation schemes for LNG ship fuel might influence the economic feasibility of the LNG compliance strategy for inland and domestic shipping.

6.3.3 Lack of infrastructure development

There is an established infrastructure of liquefaction and regasification facilities in the WCR and LNG for use as ship fuel and is theoretically available in a number of strategically located locations. In areas close to existing LNG facilities, the infrastructure developments required to enable supply of LNG as a fuel to ships is normally relatively small. For example an import terminal may include a truck loading facility from which LNG can be delivered to ships in a nearby port, or a small-scale unloading jetty may be constructed to accommodate a bunker vessel as an integrated part of the import terminal.

A number of import terminals and regasification facilities are presently planned in various WCR locations, primarily for the supply of land-based power plants, gas network for distribution to household consumers and industrial activities. These projects also contribute to favourable conditions for the establishment of infrastructure components needed for the supply of LNG as fuel for ships. An economically attractive development of an LNG infrastructure for the supply of ship fuel thus goes hand in hand, as a cost effective complement, with the development of the land-based LNG infrastructure.

Conversely, any hindrance or reduction in the development of the land-based LNG infrastructure will also influence the development of the LNG for ships negatively in the region and act as barriers. Some of the aspects identified as potential barriers are the delay of development projects due to slow permit processes, difficulties identifying relevant national authorities to handle environmental permit applications, and site selection issues. Low LNG price, though an important enabler for introduction of LNG as a marine fuel, is sometimes also referred to as a cause for shelving advanced plans for land-based LNG infrastructure projects and new liquefaction trains.

6.3.4 Optional compliance strategies

The optional SECA compliance strategies identified so far are basically LNG, MGO or use of HFO and scrubbers. It is unlikely that new other options will emerge but there is a long-term possibility that optional fuels like methanol/DME will become competitive to LNG.

The implementation of the North American ECA and the sulphur content restrictions introduced in August 2012 initiated discussions on the possibilities for waivers and exemptions from the 1% sulphur requirement. References have been made to the "compliant fuel oil non-availability"-clauses and for interim exemption during a conversion period for LNG operation. A cruising company operating in the WCR has applied for exemption referring to a scheme where some of the vessels of the operator's fleet use fuel with sulphur content below the stipulated limit whilst other vessels use non-compliant fuel resulting in a fleet average compliant level of SO_x emissions.

This type of dispositive application of the ECA regulations and scope for exemption may contribute to uncertainties in decisions on compliance strategies for ship operators and thereby act as barriers. It may, however, also facilitate and generate incentives for LNG adaptation if conditional interim waivers will be regularly issued for LNG retrofit projects.

Another aspect that may be added to the list of potential barriers is the fact that methane slip from LNG fuelled ship engines counteracts with the advantageous CO_2 emission characteristics of LNG compared with fuel oil. Recognizing that methane is 30 times more aggressive as a greenhouse gas than CO_2, this may be considered a drawback with LNG if the levels of methane slip cannot be effectively reduced by the engine manufacturers.

6.3.5 Security

The WCR includes a large number of countries also representing different political systems. Potential political disputes or conflicts in the region may temporarily influence the security of supply of LNG to some of the import facilities. This may cause temporary barriers for the development process but if one supply chain is closed it will likely be replaced by another source. Even if the LNG import price may increase, the price impact on the FOB price for LNG delivered as ship fuel may be moderate.

Some years ago the LNG import to the USA by the use of large-scale LNG carriers was criticized by opponents claiming that the LNG carriers and land-based storage tanks may constitute attractive targets for terror attacks. Today, the seriousness of these threat scenarios has, however, been toned down with reference to results from risk analyses. Large LNG carriers as well as small bunker vessels or tanks in LNG fuelled vessels are designed with double walled high strength material and the consequences of or attractiveness as targets for terror attacks are not considered significant in comparison with other handling of dangerous and flammable substances.

6.4 Enablers

6.4.1 Clear safety regulations

LNG bunkering during loading/unloading operations

It is considered important that detailed and clear-cut safety standards and regulations are established for bunkering procedures and techniques. To make LNG an attractive compliance option, it is also important that the LNG bunkering operations do not significantly influence operability of ships in terms of frequency and duration of the bunkering. In order to make LNG a feasible option for passenger vessels and ferries it is further considered necessary that safety rules and bunkering procedures are designed to allow that bunkering and embarking/disembarking of passengers can be conducted simultaneously. For general cargo vessels, container vessels and bulk carriers bunkering should also be allowed in parallel with cargo handling. For tankers and other vessels carrying dangerous cargo, bunkering operations must not be conducted during cargo transfer.

Risk-based safety zones

Requirements on how to determine safety distances and exclusion zones for bunkering operations should preferably be risk based and take into account the quantities of LNG handled, bunker flow rates and pressure, and possible credible accident scenarios.

6.4.2 Public consultation and awareness

Opposition from the public opinion is often identified as a cause of delay in LNG infrastructure development projects. Such reluctance is often based on lack of knowledge about LNG in its environmental advantages, its hazards and characteristics. Relevant information and increased public awareness may be gained by well-prepared public consultation processes as part of the site selection for intermediate LNG terminals and bunkering facilities. A number of examples where anti-LNG lobbyists have prepared and disseminated material aimed to stir fear and resistance are known from the region. To promote a shift from oil to LNG as ship fuel, information that de-mystifies LNG and presents good examples stressing the excellent safety records may form important components facilitating the process.

6.4.3 Economy and incentive schemes

Long-term LNG fuel price predictability is one important enabler. Pioneers in operating LNG fuelled vessels may initially have to pay a higher FOB LNG price but as the number of LNG fuelled ships increases, the utilization rate for bunker vessels rises and the costs related to investments in distribution infrastructure and bunker vessels may be shared by more LNG consumers.

In order to encourage pioneering projects and to speed up the introduction of LNG as ship fuel, various types of economic incentive schemes may be introduced on national basis or in cooperation between authorities, ship owners, ship operators, LNG suppliers and ports in different countries or sub regions. Successful examples of similar incentives have been designed as port fee deduction schemes, differentiated port dues and by establishment of fund mechanisms designated for financial support of emission reduction investments. If such systems are designed to unilaterally support ships of a specific flag state, it may, however, distort the competitive conditions in different shipping segments.

A number of the WCR countries are developing countries that are subject to various international aid and development cooperation programmes. Modernization of the transportation infrastructure sector is often specifically addressed in such programmes, and may possibly be expanded to include support for development of efficient SECA compliant maritime transportation systems based on LNG fuelled ships.

6.4.4 Infrastructure development

Many of the WCR countries are facing an increasing energy demand and also an increasing demand for fuel import for generation of electricity. This demand is partly fulfilled by the use of mobile floating power barges providing rapid establishment. The process of site selection, permit application, construction works, etc. for land-based facilities may take several years, while hiring an existing power barge may provide an operational system in less than one year.

If floating power barges are combined with FSRU and facilities for alongside mooring of LNG carriers, or a separate LNG import jetty, national electricity supply can be boosted significantly in WCR coastal areas and islands in an environmentally and efficient way. Such permanent or temporary infrastructural establishments may also provide important links, acting as enablers for supply infrastructure for LNG ship fuel.

6.4.5 Safe and efficient bunkering procedures and technologies

Effective interaction between manufacturers and regulators may enable adequate down scaling of established technologies from large-scale LNG handling to various concepts for LNG bunkering. Crucial system components and pieces of equipment include ESD-systems, ship-shore communication links, safe break away couplings, dry disconnection couplings, and procedures for purging and inerting bunker lines without venting of vaporized LNG, etc. In addition to prescriptive rules there is also a need for practical implementation guidelines and information on how to implement efficient and safe bunkering procedures.

7

Conclusions and recommendations for further studies

Ship traffic in the WCR is intensive with more than 100 000 registered port calls per annum. About three quarters of the registered ship movements are WCR internal movements with both departure and destination ports located within the WCR. The remaining one quarter are Panama Canal passages and calls outside the WCR. General cargo traffic dominates in the WCR but tanker and passenger traffic are also frequent.

Thirty-seven per cent of all registered port calls are from ships calling at ports located within the present North American ECA and when the US Caribbean ECA comes into effect in 2014, an additional 9% of the calls will be at ports located within ECAs. This is the basic scenario for the feasibility study but for future scenarios it is anticipated that the extent of the ECAs in the WCR will expand and possibly cover the entire WCR.

Decided future expansion and possible additional further expansion of the ECAs in the WCR will gradually increase the attractiveness of the option to use LNG as ship fuel.

The price of LNG in the WCR market is favourable in relation to conventional fuel oils and in particular in relation to MGO, which is an optional "wait and see" strategy for ECA compliance. One key issue of feasibility for introduction of LNG as ship fuel is the expected additional cost for making the LNG available as a bunker fuel in the areas where the ships are operating. These costs are highly dependent on the existing land-based LNG infrastructure and the plans and prospects of future expansion of this infrastructure. Today LNG terminals are found on the US mainland, in Mexico, Trinidad & Tobago, the Dominican Republic and in Puerto Rico. Many of the WCR island nations have started implementing energy strategies based on increased use of natural gas for electricity production to cover increasing national energy demands. For the WCR island nations, import of LNG is often considered the most feasible way for supply but subsea gas pipelines are also discussed in some places. As part of this long-term implementation process, a number of LNG import terminals of various type and size are currently being planned and may form a basis for an efficient and economically attractive solution for an LNG infrastructure dedicated for the supply of LNG as ship fuel. Additional facilities for truck loading, for loading of bunker vessels or LNG feeder vessels in the LNG terminals are needed to form a basic infrastructure network for distribution and supply of LNG as ship fuel. Given that such additional facilities can be established at reasonable costs and utilized at high capacity, an attractive LNG FOB bunker price can be ensured in many places in the WCR.

In addition to the LNG FOB price, other key feasibility issues for introduction of LNG as ship fuel are related to the ships' long-term geographical operational areas. Some ship segments and fleets are designed for a specific route or engaged for long time charters and will basically operate in the WCR during its entire life cycle, while other ship types frequently are engaged in other routes and must be economically operational also in areas where LNG is not available.

The economic and technical feasibility aspects of different ships and ship segments also vary significantly with regard to age of the vessel or expected remaining lifetime and possibilities for conversion/retrofit of LNG versus the prospects and need for new building and replacement tonnage. Some ship segments, in addition to regulatory compliance requirements and commercial aspects also need to consider external environmental pressure and demand in their assessment of LNG and its potential competitive advantages.

A number of the identified short sea and coastal shipping segments are considered suitable for introduction of LNG as fuel but not only typical short sea and coastal segments may become early adopters due to attractive operational and commercial conditions.

PSV (Platform Support Vessel) in the WCR is a category considered to be suitable with respect to additional cost for LNG supply infrastructure. It is also considered suitable with regard to its operational area, the demand for newbuilding and external environmental demand and shows an overall high suitability for introduction of LNG as fuel.

A second WCR segment in which early LNG adopters are considered likely to be presented is for newbuildings in the cruising segment. Retrofit projects for LNG conversion of cruise vessels are costly but may also be feasible. In the small passenger ferry segment, the specific ferry service between the islands Trinidad and Tobago was identified as an interesting example of particular suitability for adoption of LNG as fuel.

Container feeder vessels are expected to gain an increasing market for WCR internal cargo transportation while the traditional general cargo sector probably will decrease. The location of the container hub ports in the WCR and possible WCR feeder routes are considered suitable for services with LNG fuelled vessels, and for new building projects of container feeders, LNG can be assumed to be an attractive option.

Another WCR ship segment that is in contrast to the ones above, not associated with very high conversion costs for introduction of LNG fuel, is the tanker segment. LNG is considered a possible attractive option for the route carrying crude from the northern coast of South America to the oil terminals in the US Gulf with Aframax tonnage. Even if only a minor part of this route is within ECA, LNG retrofit projects and full-time LNG operation may be found economically attractive compared with HFO-MGO swapping strategies. The fleet of coastal tankers operating with supplying various fuels to the islands in the eastern Caribbean Sea is another part of the WCR tanker segment that may include early adopters provided that an LNG bunker infrastructure will be established in the area.

Based on the ship segments identified as feasible for introduction of LNG, a number of indicative quantitative examples has been derived and presented in the report. An approach for estimation of future LNG demand is outlined based on a timeline and scenarios of gradually increasing LNG adoption rate. Examples of required additional LNG bunker distribution infrastructure, bunker vessels, etc. are also presented, indicating that introduction of LNG as ship fuel in the WCR is feasibility and that there are good prospects for LNG to become an attractive fuel option for specific ships segments operating in the WCR.

The presented analysis approach would require a lot of detailed calculation efforts to provide overall quantitative figures for the entire WCR and it would still be associated with a number of uncertainties related to adaptation rates, etc. If a more detailed study should be accomplished in the future it would also be valuable to examine the changes in the traffic patterns and statistics by comparing the 2007–2008 REMPEITC data used in this study with more recent data.

The presented examples together with the general suitability and trend analyses are, however, considered to provide a good overview of the possibilities and limitations for introduction of LNG as ship fuel for short sea and coastal shipping in the WCR and the feasibility for establishment of an LNG bunkering infrastructure.

8
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IMO is the specialized agency of the United Nations with responsibility for ensuring that lives at sea are not put at risk and that the environment is not polluted by international shipping. The Convention establishing IMO was adopted in 1948 and IMO first met in 1959. IMO's 171 member States use IMO to develop and maintain a comprehensive regulatory framework for shipping. IMO has adopted more than 50 binding treaty instruments, covering safety, environmental concerns, legal matters, technical co-operation, maritime security and the efficiency of shipping. IMO's main Conventions are applicable to almost 100% of all merchant ships engaged in international trade.

This publication contains the following:

1) Feasibility study on the use of LNG as a fuel for international shipping in the North America Emission Control Area (ECA)

2) Pilot Study on the use of Liquefied Natural Gas (LNG) as a fuel for a high-speed passenger ship from Port of Spain ferry terminal in Trinidad and Tobago

3) Feasibility Study on LNG Fuelled Short Sea and Coastal Shipping in the Wider Caribbean Region

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