Asia-Pacific
Economic Cooperation

Study on Clean Energy Shipping with LNG Fuelled Ship

Transportation Working Group (TPT-WG)

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Contents

1. Why LNG as a Marine Fuel

1) Introduction

Natural gas is considered the cleanest of the fossil fuels. Burning it creates few by-products except for carbon dioxide (CO2), nitrogen oxides (NOx) and water. It is widely used for cooking, heating, power generation, industrial purposes like producing steel, glass, forest products, clothing, cement, fertilizer and petrochemicals. Natural gas is also extensively used to fuel vehicles.

Since the beginning of the 21st century, there has been increasing global interest in switching to liquefied natural gas as an alternative marine fuel. Its technical readiness, affordability, abundance and significantly lower emission mean that LNG is well positioned to enter commercial use for marine fuel.

LNG

LNG is liquefied natural gas, a clear, colorless, non-toxic liquid that forms when natural gas is cooled to -162ºC (-260ºF). LNG has been produced commercially since 1940 as a method of transporting stranded natural gas to consumers where distribution via pipeline was not possible.

Main general physical and chemical characteristics of LNG

Color	Colorless
Odor	Odorless
Molecular weight	16.0425g
Density	6.6715E-4kg/m3 (at 20º Celsius)
Boiling point	-161.48º Celsius
Vapor density	0.55 (relative to air)

From a societal perspective, perhaps the primary motivation to support the adoption of a new marine fuel, switching from traditional fuel oils to LNG would result in significant health and environmental improvements without a significant increase in the cost of transportation.

In marine applications, LNG provides significant benefits in terms of reducing emissions from ship engine exhaust. When compared with modern engines using even “clean” fuel oils, LNG can lower ship exhaust emissions of sulphur oxides (SOx) by over 90%; of nitrogen oxides (NOx) by up to 35% for diesel cycle engines and up to 85% for Otto cycle engines; of particulate matter (PM) by over 85%; of carbon dioxide (CO2) by up to 29%; and of greenhouse gases (GHGs) by up to 19% on a CO2-equivalent basis.

In contrast, the traditional marine fuel consisted of oils of poor to very poor quality produce many gaseous emissions and PM, which have undesirable effects on human health and on the environment.

Traditional Marine Fuel

✧ Heavy fuel oils

The most common fuel for marine operations has traditionally been heavy fuel oil (HFO). HFO is considered a residual product, since it remains after the more valuable components of crude oil have been extracted through refining. It contains a wide range of contaminants, such as ash, sulphur and sodium, which makes its post-combustion exhaust a danger to the environment and to human health.

✧ Marine distillates

These are marine diesel oil (MDO) and marine gas oil (MGO) which contain lower concentrations of s ulphur than HFO, permissible sulphur content by weight has remained quite high, at 2.0% and 1.5% r espectively.

Fire Hazard Properties of LNG and Other Fuels

Properties		Petrol(100 Octane)	Diesel	Methane(LNG)	Propane(LPG)
Flash point(ºC)		< -40	>62		
Flammability in air	Lowest concentration in air (%)	1.4	0.6	4.5	2.1
	Highest concentration in air (%)	7.6	7.5	16.5	9.5
Auto-ignition temperature(ºC)		246-280	250-300	537	480

LNG Vs Traditional Marine Fuel

<table>
<tr><th>Compliance Option</th><th>LNG</th><th>HFO</th><th>MDO/MGO</th></tr>
<tr><td>CO2 removal</td><td>10-20%</td><td rowspan="4">Abatement technologies</td><td>No</td></tr>
<tr><td>SOx removal</td><td>100%</td><td>MDO: <2%
MGO: 0.01-1%</td></tr>
<tr><td>NOx removal</td><td>Up to 80-90%</td><td rowspan="2">Abatement technologies</td></tr>
<tr><td>Particulate matter</td><td>98-100%</td></tr>
<tr><td>Regulation in place</td><td>Developing</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Infrastructure</td><td>Early Stages</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Cultural factors</td><td>Higher</td><td>Established</td><td>Established</td></tr>
<tr><td>Cost of use</td><td>LNG Storage tank size: LNG fuel price uncertain; possible loss of cargo space</td><td colspan="2">Abatement technologies required</td></tr>
<tr><td>Potential to stretch the technology</td><td>Further CO2 reduction</td><td colspan="2">End of Cycle</td></tr>
<tr><td>Challenges/ differences</td><td>Bunker space/ cyrogenics/ possible methane slip</td><td colspan="2">Abatement technologies
Varied blends of distillates 2020</td></tr>
</table>

2) Review of Environmental Regulations

The IMO

As a specialized agency of the United Nations, IMO(the International Maritime Organization) is the global standard-setting authority for the safety, security and environmental performance of international shipping. Through its environmental convention (MARPOL), it regulates pollution of the oceans and seas, including dumping, oil and air pollution.

MARPOL Annex VI (Air Pollution Annex) which is first enforced on May 19, 2005 limits the main air pollutants contained in ships exhaust gas, including SOx and NOx, and prohibits deliberate emissions of ozone depleting substances (ODS).

The Revised MARPOL Annex VI, which is first adopted in 2008 and started to be enforced in 2010, significantly strengthened the regulation on emissions of SOx, NOx and particulate matter from ships.

Under the revised MARPOL Annex VI, the global sulphur cap will be reduced from current 3.50% to 0.50%, effective from 1 January 2020, subject to a feasibility review to be completed no later than 2018. The limits applicable in ECAs for SOx and particulate matter were reduced to 0.10%, from 1 January 2015.

SOx and PM Regulation

Outside an ECA established to limit SO_X and particulate matter emissions	Inside an ECA established to limit Sox and particulate matter emissions
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020	0.10% m/m on and after 1 January 2015

Note: ECA for SOx currently refers to Baltic Sea area, North Sea area, North American area, 4 and United States Caribbean Sea area

Source: IMO

Under the revised MARPOL Annex VI, NOx emissions from marine diesel engines installed on ships are required to be reduced progressively in 3 steps. Ships constructed between

2000~2010 are required to be complied with "Tier I" emission limit. "Tier II" regulates engines installed on a ship constructed on or after 1 January 2011. A more stringent "Tier III" which requires more than 70% NOx emission of current stage (Tier II) to be further reduced is for engines installed on a ship constructed on or after 1 January 2016 operating in ECAs

Note: ECA for NOx currently refers to North American Emission Control Area and the U.S. Caribbean Sea Emission Control Area

NO_x Regulation

Tier	Ship Construction date on or after	Total weighted cycle emission limit (g/kWh) n=engine's rated speed (rpm)		
		N<130	n=130-1999	n≥2000
I	1 January 2000	17	$45 \cdot n^{(-0.2)}$ e.g., 720rpm → 12.1	9.8
II	1 January 2011	14.4	$44 \cdot n^{(-0.23)}$ e.g., 720rpm → 9.7	7.7
III	1 January 2016	3.4	$9 \cdot n^{(-0.2)}$ e.g., 720rpm → 2.4	2

Source: IMO

In addition, ECA has been increased in recent years. The ECA for SOx is Baltic Sea area which came into effect in 2006. After that, North Sea area become an ECA in 2007, followed by North American area in 2012 and United States Caribbean Sea area in 2014. Other areas might be designated as new ECAs in the future.

ECA areas

Adoption, entry into force & date of taking effect of Special Areas(Annex VI)			
Special Areas	**Adopted**	**Date of Entry into Force**	**In Effect Form**
Baltic Sea(So_x)	26 Sep 1997	19 May 2005	19 May 2006
North Sea(Sox)	22 Jul 2005	22 Nov 2006	22 Nov 2007
North American ECA (Sox and PM)	26 Mar 2010	1 Aug 2011	1 Aug 2012
(Nox)	26 Mar 2010	1 Aug 2011	-
United States Caribbean Sea ECA (Sox and PM)	26 Jul 2011	1 Jan 2013	1 Jan 2014
(Nox)	26 Jul 2011	1 Jan 2013	-

Source: IMO

Increased Environmental Concerns and Possible Expansion of ECA Areas

Source: DNV-GL

In 2011, IMO adopted mandatory technical and operational energy efficiency measures which are expected to significantly reduce the amount of CO2 emissions from international shipping. These mandatory measures are the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships, both entered into force on 1 January 2013.

SEEMP is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner. The SEEMP also provides an approach for shipping companies to manage ship and fleet efficiency performance over time using. These two measures urge the ship owner and operator to consider new technologies and practices when seeking to optimize the performance of a ship.

Recently, IMO is considering adopt some new market-based measures for further control of GHGs emission in order to meet international society’s need.

Proposals on Market-based Measure

MBM Proposal Title	Proposed by	Mechanism Summary
International GHG Fund (GHG Fund)	Denmark etc.	Establish an international GHG Fund by money raised through taxation on fuel oil for ships
Emission Trading System (ETS)	Norway etc.	Introduce a trading system of CER(Certified Emission Reduction) for ships.
Efficiency Incentive Scheme	Japan, WSC	New-building: Increase EEDI standard. Tax exemption for ships meet increased EEDI standards. Existing Ships: Taxation on fuel oil
Ship Efficiency & Credit trading (SECT)	USA	Adopting efficiency standard for existing Ships Create a efficiency credit trading system - efficient ships to sell credit and non-efficient ships to buy credit
Rebate Mechanism (RM)	IUCN, WWF	Taxation on GHG emission Establish a rebate mechanism to compensate developing economies according to their import value through shipping
Port State Levy (PSL)	Jamaica	Taxation on GHG emission through port state
CO2 Emission cut target	Bahamas	Introduce emission cut target by ship age
Speed-related GHG or Compensation Fund	CSC	Regulation on maximum voyage speed

Source: IMO

Regional Level

Some advanced economies adopt more strengthened emission control regulation on ships than IMO.

USA

As the biggest cruise ship port in the USA, the state government of California established its own regulations on SOx Emissions and prohibits use of HFO as a fuel for ships entering ports in its jurisdiction.

State of California's Regulations on SOx Emissions

Application Area	Date	Sulfur Limit in Fuel
24 Nautical Mile zone	2009.7.1~2011.12.31	MDO: less than 0.5% m/m MGO: less than 1.5% m/m
	2012.1.1~	MDO: less than 0.1% m/m MGO: less than 0.1% m/m

EU

EU Council also has its strengthened Standard on SOx emissions in all EU ports. Currently it requires all ships entering EU ports using fuel with SOx emission less than 0.1% m/m.

EU SOx Emissions Limit Standard

Date	EU Reg.	Area	Ship Type	Sulfur Limit in Fuel
2008.1.1	1999/32/EC 2005/33/EC	EU Ports	ALL	MGO: less than 0.1% m/m
2010.1.1	2005/33/EC	EU Ports	ALL	All Fuel: Less than 0.1% m/m

Hong Kong

Recently Hong Kong government requires all ships bigger than 500 G/T to use fuel oil of less than 0.5% of sulfur content entering Hong Kong port. This Air pollution Management Regulation was enforced since July 1, 2015.

3) The Promising Solution, LNG

Global interest in using LNG as marine fuel continues to grow as many believe LNG allows compliance with all current and known future emission requirements.

In the short term, ship owners and operators are switching from traditional residual bunker fuel during ocean passages to low sulfur fuels when operating in ECAs. For the longer term ship owners are studying alternative approaches to meet the environmental requirement for the post 2020 or 2025 era.

Options for them include:

- Secure a reliable and affordable source of low sulfur liquid fuel oil such as MDO and MGO
- Consume high sulfur fuel and add emission reduction equipment such as scrubbers to meet requirements
- Shift to an alternative low sulfur fuel

LNG is one alternative attracting attention because of its low sulfur content and its price, which is lower than the traditional residual oil based bunker fuels. The abundance and technology readiness also contribute to LNG as a promising marine fuel.

Options to Be Compliance with MARPOL Annex VI

Options	**Low sulphur fuel oil MDO/MGO**		**Scrubber + High sulphur fuel**	**LNG**	
Issues	Low sulphur fuel availability	Price relative to alternatives	Installation cost, waste disposal, high sulphur fuel cost	LNG equipment costs, conversion time and cost	LNG, LNG bunker facility availability and cost
Pros	+No extra fuel tanks or handling needed		+Scrubbers available +HFO and bunkering facilities available +Fuel price	+Meets SO_x, particulate and NO_x requirements	

Cons	- Higher fuel costs - Scrubbers needed to meet Tier Ⅲ NOx - Low sulphur fuel availability and cost - Ships required to use low sulphur fuel, but refiners not required to produce/supply	- Capital investment - Off hire time for Conversion - Waste disposal facility availability and cost	- More shipboard storage capacity required - Capital investment in LNG equipment - Limited areas where LNG fuelling facility availability

Source: Frederick Adamchak, "LNG as marine fuel"

2. Regulation Framework

Interest in using LNG as a fuel for ships has been developed faster than the regulatory framework to govern it. Although the international level unified regulation system is still under developing, the IMO, ISO and classification societies published some guidelines and technical standards to follow.

1) IMO

IMO IGC Code (International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk) regulates the operation of LNG carriers and handling of LNG as cargo. IMO also has Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships, which will soon replaced by the IGF Code (International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels) regulating safety and operational issues for LNG fuelled seagoing ships

2) ISO

Although ISO/TC 18683, Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships, is not yet an international standard, these draft guidelines provide guidance on bunkering facilities, ship/facility interfaces, procedures for connection and disconnection, emergency shutdown and bunkering process control.Other technical standards such as ISO 28460:2010, ISO 10976:2012 can also be applied to LNG fuelled ships and LNG bunkering.

3) Classification Societies

Classification Societies are non-government organizations that set and maintain technical standards for the design, construction, and operation of ships. DNV firstly published its rules on LNG fuelled ships early in 2000 when the first LNG fuelled passenger ship in the world “Grutra” was built. After that many classification societies especially IACS members have modified their rules to cover LNG fuelled ships. Currently LNG bunkering and operation of LNG bunkering stations are not regulated under a unified international regulatory framework. Instead they are usually regulated by independent port authorities under regional regulation or rules. Lack of international standards may limit the development of LNG fuelled ships and may also imply technical barriers for developing economies. Thus IMO and ISO are putting efforts on building up the international regulatory framework.

Regulation References on LNG Fueled Ships

- Marine Fuel Regulations

  1) IMO Interim Guidelines for gas as ship fuel (MSC.285(86))
  2) IMO – IGF Code under development : Rules for the receiving ship, the ship using LNG as fuel
  3) IMO – IGC Code “Liquefied gas carriers” : Rules for the bunker boat, which is a small LNG carrier
  4) ISO/TC 67/WG 10 PT1 under development by IMO, SIGGTO, OCIMF: Guidelines for LNG transfer and Port Operation, Guidelines for oil transfer, ship-to-ship oil bunker procedures
  5) Port regulations : USCG, “Green bunkering” for Port of Gotenborg
  6) Onshore regulations : EU, NFPA, FERC, DBS

- Ship-building and Bunkering Related Regulations

  1) IMO(International Maritime Organization)
     - SOLAS convention
     - STCW convention
     - IGC Code
     - IGF Code
     - MSC. 285

  2) ISO(International Organization for Standardization)
     - ISO 18683 Guidelines for systems and installations for supply as fuel to ships
     - ISO 28460:2010 Installation and equipment for liquefied natural gas-ship to shore interface and port operations
     - ISO 10976:2012 Refrigerated light hydrocarbon - measurement of cargoes on board LNG carriers

- ISO 16903 Characteristics of LNG influencing design and material selection
- ISO/IEC 31010:2010 Risk management - Risk assessment techniques
- ISO 17776 Guidelines on tools and techniques for hazard identification and risk assessment
- ISO 16901 Guidance on performing risk assessment in the design of

3) SIGTTO(Society of International Gas Tanker & Terminal Operator)
   - LNG Ship to Ship Transfer Guidelines
   - Liquefied Gas Fire Hazard Management
   - ESD arrangements and linked ship/shore systems for liquefied gas carriers
   - Liquefied Gas handling principles on ships and in Terminals
   - LNG operation in Port Areas

4) OCIMF(Oil Companies International Marine Forum)
   - International Safety Guide for Oil Tankers & Terminals (ISGOTT)
   - Ship to Ship Transfer Guide (Liquefied Gases)
   - Ship Inspection Report Programme (SIRE)

5) CEN(The European Committee for Standardization)
   - Installation and equipment for liquefied natural gas – general characteristics of liquefied gas and cryogenic materials
   - Installation and equipment for liquefied natural gas – Design of onshore installations including those liquefaction, storage, vaporization, transfer and handling of LNG
   - Installation and equipment for liquefied natural gas – Design of onshore installations with a storage capacity between 5t and 200t
   - Design and manufacture of site built, vertical, cylindrical, flat – bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 to – 162 ℃
   - Installation and equipment for liquefied natural gas

6) NFPA(National Fire Protection Association)

- Standard for the Production, Storage and Handling of Liquefied Natural Gas (LNG), Including for plant siting and layout for process equipment, stationary LNG storage, training and performance of risk assessment
- Fire protection standard for pleasure and commercial motor craft including requirements for design and for safety for boat less than 300 gross tons
- LNG Vehicular Fuel System Code

7) Classification regulation

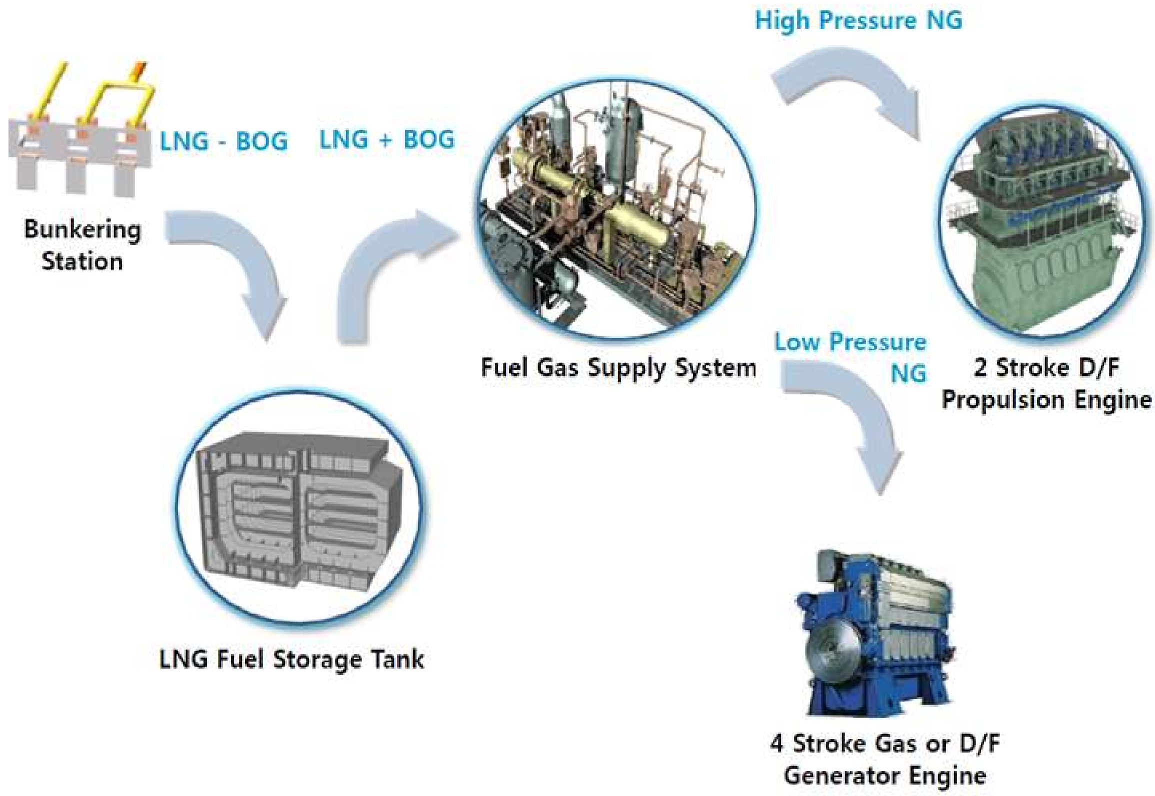
- ABS: Guide for propulsion and auxiliary systems for gas-fuelled ships
- BV: Safety rules for gas-fuelled engine installations in ships; Rule not NR529 DT R01 E
- DNV: Gas-fuelled engine installations
- GL: Guidelines for the use of gas as fuel for ships
- DNV-GL: Development and operation of LNG bunkering facilities
- KR: Guidance for gas-fuelled ships
- LR: Rules and regulations for the classification of natural gas-fuelled ships
- NK: Guidelines for the issuance of ship fuel gas
- PRS: Guidelines of safety for natural gas-fuelled engine installations in ships; publication No. 88/P
- RINA: Rules for the classification of ships, Amendments to part C, Chapter 1: New Appendix 7- Gas-fuelled ships

3. Technology Readiness

1) LNG Propulsion Systems

The propulsion systems are the means by which the engine's power moves the ship. LNG propulsion systems incorporate subsystems which are not typically found on conventionally fuelled vessels. The LNG engines also have very unique operating characteristics which differ with the traditional engines. Thus for LNG fuelled ships, the propulsion systems usually contain LNG engine, fuel gas supply system, LNG tank and the pipes, valves, pumps and safety equipments. All these equipments are required to be able to endure very low temperature.

LNG Fueled Propulsion System for Large Commercial Ships



Source: Daewoo Shipbuilding & Marine Engineering Co., Ltd.(DSME)

2) Engine Technologies

Natural gas engines have been used for many years both on land and aboard ships. There are also abundant options exist for engines of merchant vessels. However, at current stage, dual fuel engines is more extensively used than LNG-only engines, not only because of its technology readiness but also of its flexibility in deciding which fuel to use, based on fuel price and availability.

Dual fuel engine manufactures include Mitsubishi, Wärtsilä, Rolls-Royce, MAN Diesel & Turbo (MAN D&T) and etc. Among them, Wärtsilä and Rolls-Royce also provide package service of the whole propulsion system together with ship design.

Currently most popular engines for LNG fueled ships are 2-stroke engines. Two-stroke natural gas-fuelled engines have been available for the market since late 2012. First mover is MAN, who presented their ME GI engine at HHI on 9th of November 2012. The second big player is Wärtsilä who sold their first dual-fuel two-stroke engines in 2014.

Engine is the most important part of a ship, given relatively small number of ships running on LNG currently, study and comparison of these 2 engines is crucial to ship owners to make the decision.

Diesel or Otto

All gas engines conform to either the “Diesel” cycle or the “Otto” cycle. The Diesel cycle, also known as a “compression – ignition” cycle, relies on the heat created by compression in the cylinder of a diesel fuel spray to self-ignite the gas. For “Otto” cycle, pure gas is ignited by a spark plug with no requirement of diesel.

Three Engine concepts for LNG fuelled ships

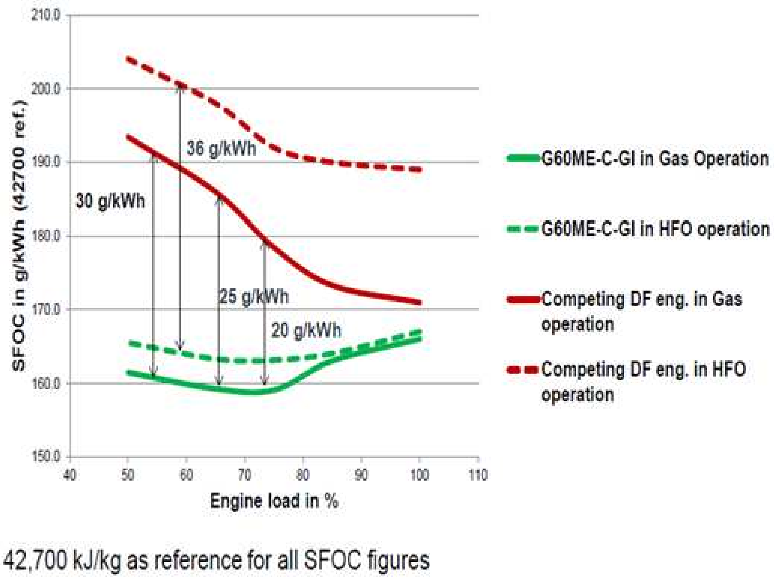
- Spark Ignited Lean Burn Engine (Otto cycle)
- Dual Fuel Engine (Combined Otto/Diesel cycle)
- High Pressure Direct Injection Engine (Diesel cycle)

MAN D&T ME-GI Engine

ME-GI Engine is operated by “Diesel” cycle. Use the heat created by compression in the cylinder of a small injection of diesel to self-ignite the gas. The explosive pressure rise pushes the piston downwards and powers the engine.

Different to DF Diesel engine (Dual Fuel Diesel Engine) which ask ship owners to chose one between diesel and LNG for fuel at a certain period, ME-GI engine actually use the fuel mixed by diesel and LNG at a certain percentage. Thus ME-GI engine is relatively fuel efficient. Due to its high fuel efficiency, ME-GI engine is able to meet ECA limits after exhaust gas reduction equipments.

SFOC Comparison of ME-GI Engine and DF Diesel Engine



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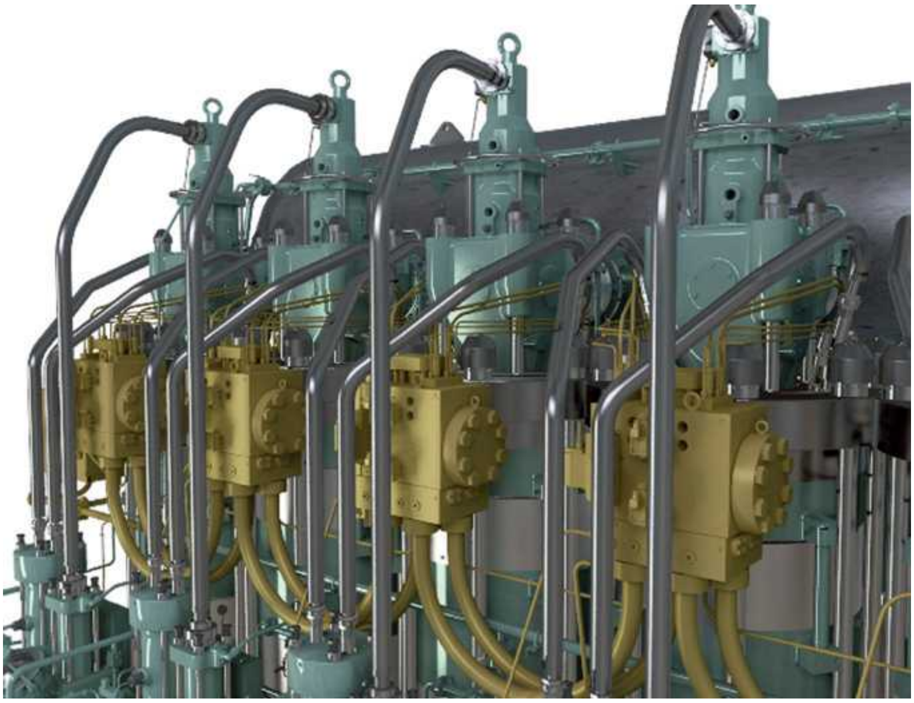
Source: IMO

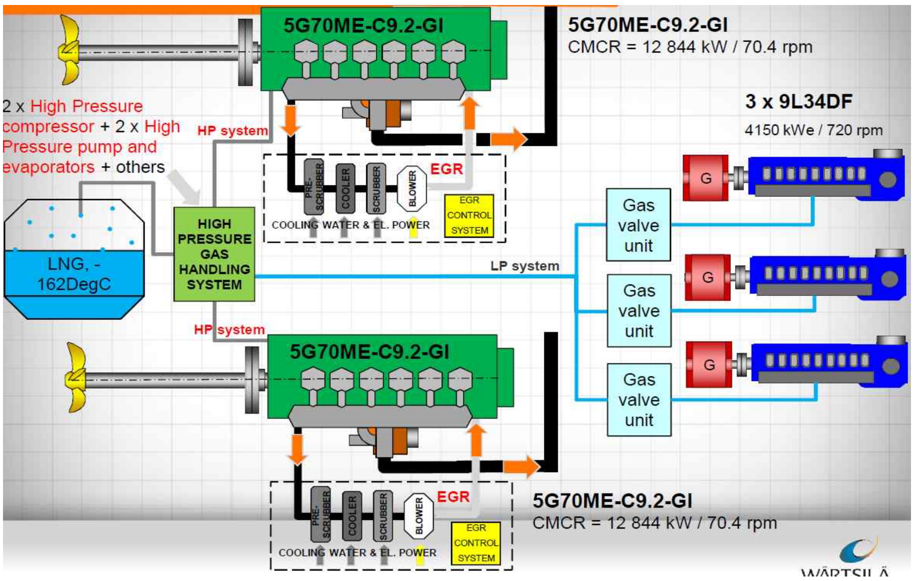
ME-GI engine can operate regardless of LNG quality because diesel assist it to burn the gas, thus it provide a good solution of low quality gas such as the Shale. Besides for ships installed with MC&ME engines, conversion to ME-GI engine will be easier.

Injection system of ME-GI Dual Fuel MAN B&W Engine



Source: MAN B&W

Engine room configurations from MAN B&W



Source: Wärtsilä

Track Record

The first order of ME-GI engine is made by Totem Ocean Trailer Express. It is a contract of two 3,100TEU container ships with options for up to three additional ships built in NASSCO of San Diego. The first ship, named as 'Isla Bella' which was launched in April, 2015 and become the first LNG fuelled container ship in the world. Isla Bella is expected to be delivered after sea trial late this year. And the second ship is scheduled for completion in 2016.

Specification of Isla Bella

Vessel technical Specifications		Propulsion Plant	
Length	232.87 m	Main Engine Type	Dual Fuel Slow Speed
Breadth	32.31 m(Panamax)	M/E Model	MAN B&W 8L70ME-C8.2-GI
Depth	18.29 m	M/E MCR	25,191 kW × 104.0 rpm
Draft	10.36 m	M/E NCR	21,412 kW × 98.5 rpm
Speed	22.0 kts	Aux/E Type	MAN 3 × 9L28/32 GenSets

The 3,100 TEU ships are designed by DSEC, a subsidiary of Daewoo Shipbuilding & Marine Engineering (DSME) in Korea. A single MAN B&W 8L70ME-GI dual-fuel gas-powered engine is installed together with the high pressure LNG fuel supply system developed by Korean yard.

Isla Bella

Source: TOTE Maritime

The second application is five LNG carriers ordered by Teekay. The first ship of this series will be completed in 2016

Teekay Fuel-Efficient LNGC

Matson's order on ME-GI engines for its 3,600TEU container ships(2+5) of marks the biggest current dual-fuel engine. The specification reaches 7S90ME-GI, 42700kW (57,000HP).

Matson 3,600TEU LNG Fuelled Ship

In addition, many existing ships are conversion into LNG fuelled ship by installing NE-GI engines.

ME-GI Engines Ordered by Conversion Purpose

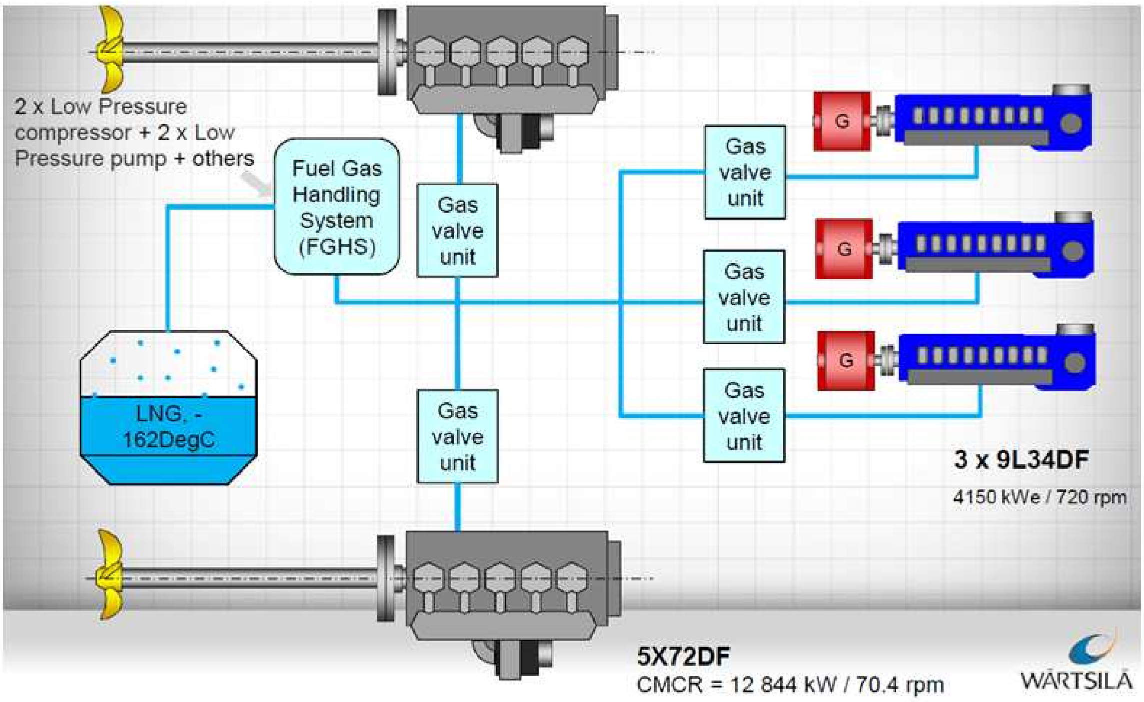
Ship Yard	Information	No. of ship	Remark
NASSCO	American Petroleum Tankers	4	Tanker
NASSCO	Seacor	2	Tanker
Aker Philly	Crowley	4 + 4	Tanker
ALL	Jones Act ocean-going ship		

Wärtsilä 2-stroke Engine

Wärtsilä 2-stroke Engine, which adopts "Otto" cycle for gas, is designed on redundancy concept. The Wärtsilä engines inject the gas at the beginning of the compression after the air has entered the cylinder. At the low pressure at the beginning of compression, only a low gas pressure is required. The gas/air mixture is ignited at the end of the compression stroke by the pilot oil.

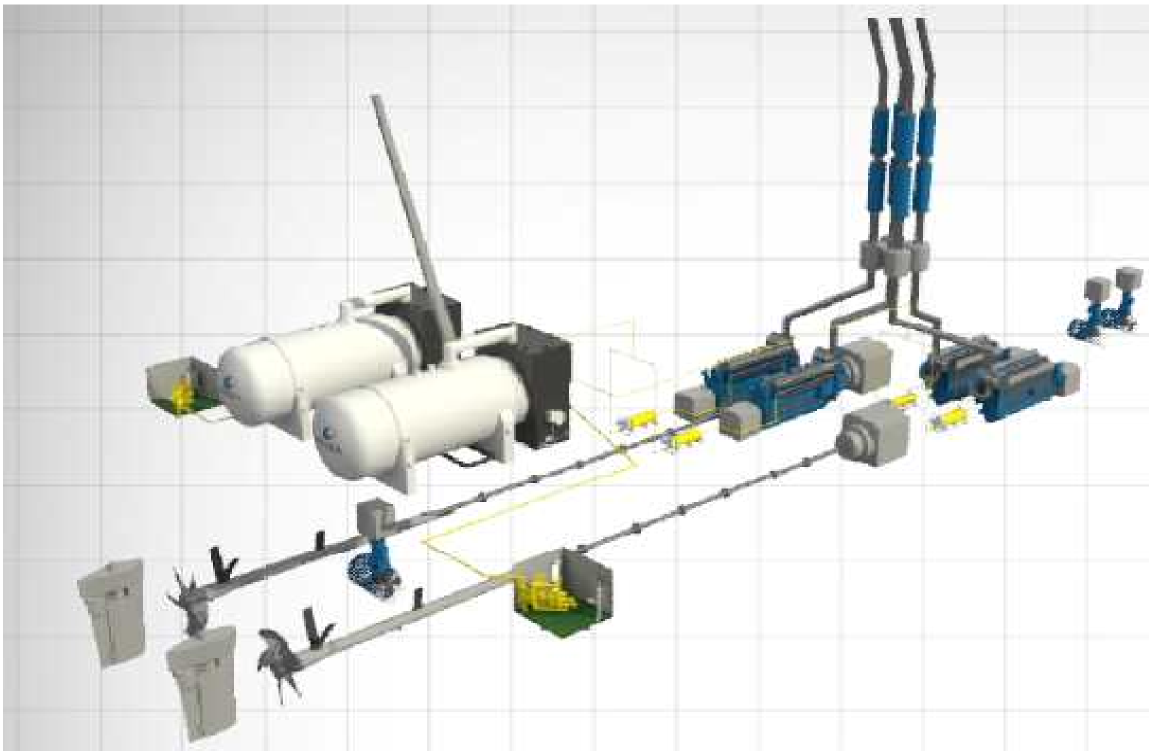
This engine is able to switch from gas fuel into oil at anytime or vice versa. However, the combustion process should also be changed when fuel is switched. Due to different combustion characteristics, output and performance and the limitation of knocking/pre-ignition, combustion chamber is required to be added into the system. The advantages of Wärtsilä 2-stroke Engine are low maintenance cost and easy to installation.

Engine Room configurations From Wärtsilä



Source: Wärtsilä

W-X & RT-flex Wärtsilä Dual Fuel Engine



Source: Wärtsilä

Track Record

Representative application of Wärtsilä engine is Tarbit Shipping's 25,000 dwt tanker named 'Bit Viking'. It is claimed to be the world's first product tanker to be converted to LNG from HFO fuelled. After the conversion of main machinery, the vessel was re-delivered to her owner in October 2011.

The ship has two engine rooms, propellers, steering gears, rudders and control systems. She has twin screw propulsion. Each of these was previously being powered by a six-cylinder in-line engine operating on HFO. The conversion involved swapping these with six-cylinder in-line Wärtsilä 50DF dual-fuel engines running on LNG. Each of the two LNG fuelled engines is capable of producing 5,700kW at 500rpm.

Bit Viking Installed with a Wärtsilä Engine

Source: DNV-GL

Besides, Terntank has four LNG powered 15,000 dwt product tankers installed of Wärtsilä engines on order at the Chinese shipyard Avic Dingheng Shipbuilding Co., Ltd. Zhejiang Huaxiang Shipping Co.Ltd., a Chinese owner, also ordered their new LNG carrier to install with Wärtsilä 2-stroke engine. After delivery in August 2015, the 14,000 cubic metre LNG carrier will operate along the Chinese coastline to serve domestic LNG transportation lines

Comparison of ME-GI Engine and Wärtsilä 2-stroke Engine

ME-GI engine has the advantage of high fuel efficiency and is almost free from problem of methane slip. Instead, gas reduction equipments such as EGR and SCR should be added to further reduce NOx emission in order to meet IMO Tier III requirements.

While the dual fuel engine from Wärtsilä can better meet the emission requirements with lower operation cost and easier installation but have weakness in fuel efficiency and methane slip.

Comparison Between ME-GI Engine And Other Combustion Ways

	Diesel cycle	Otto cycle	
Engine type	Gas injection (ME-GI)	Spark ignition	Dual Fuel
Gas running load range	0 to 100% load	0 to <100% load	0 to <100% load
Gas injection pressure	300 bar	5-7 bar	5-7 bar
Gas quality/requirements (LCV)	Insensitive	Sensitive	Sensitive
Methane number dependant	No	Yes	Yes
NOx	Below Tier II	Below Tier III	Below Tier III
Tier III Gas Mode	Exhaust gas after-treatment (EGR or SCR) required	Exhaust gas after-treatment not required	
NOx reduction according to Tier III	All fuels	Only gas	Only gas
Methane slip	0.1% of SFOC	2-4% of SFOC	2-4% of SFOC
GWP	Reduced by 20%	Increased	Increased
Fuel Gas Handling system layout; ➢ Heaters ➢ Evaporators ➢ Piping system ➢ Valves ➢ Sensors ➢ LNG cryogenic ➢ pumps	Designed for a pressure of 300 bar -> High impact on safety in case of leakage	Designed for a pressure of 300bar -> High impact on safety in case of leakage	
Investment costs	High	Low	
Maintenance	Demanding, High costs	Easy	

Comparison between MAN D&T and Wärtsilä in Gas Supply system

MAN D&T(ME-GI)	Wärtsilä
High Pressure Installation	Low pressure installation
Mechanical	Mechanical or electric
Diesel Principle in gas mode	Otto Principle in gas mode
Exhaust Treatment needed for compliance	NOx and Sox ECA compliant

3) LNG Fuel & Storage Tank

LNG needs to be stored at very low temperature (approximately at -163℃) to keep the fuel in liquid form. Besides LNG storage tank should be sustainable even under high load during voyage. LNG as a fuel should be supplied to the engine both smoothly and safely.

There are several different types of LNG fuel storage tanks. According to IMO IGF Code, LNG tanks can be independent tanks, which include Type A, B and C tanks. LNG tanks also can be non-independent tanks, which include the membrane and semi-membrane types.

Independent Tanks (Types A, B and C)

Independent LNG tanks, which are self-supporting tanks that do not rely on the ship's structure for strength.

Type A tanks are designed primarily using recognized standards of classical ship structural analysis and constructed of a plane surface and are prismatic in shape. The Code limits this type of tank to a vapor pressure of less than 0.7 bars, and where minimum design temperature is below -10°C (14°F), requires a complete secondary barrier capable of containing the cargo for a period of 15 days in the event of a ruptured or leaking tank.

Type B independent tanks are defined as "designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics." Type B independent tanks can be spherical or prismatic shaped tanks. One of the key characteristics for Type B designation is compliance with the "leak before failure" concept, under which crack propagation analysis by fracture mechanics techniques must demonstrate that if a crack in the system should develop, its growth will not be rapid enough to allow excessive leakage into the cargo hold. A partial secondary barrier, which can consist of a spray shield and drip pans, is required for independent Type B tanks with minimum design temperatures below -10°C (14°F).

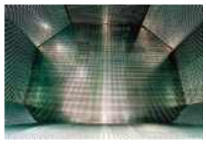
Type C tanks are pressure vessels which are designed for pressures greater than 2 bar and are cylindrical or spherical in shape. Type C tanks can be designed for much higher vapor space pressures than Type A and Type B tanks. A secondary barrier is not required.

Non-independent Tanks (Membrane)

Membrane tanks are non-self-supporting tanks which consist of a thin layer (membrane) supported through insulation by the adjacent hull structure. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane. This containment system includes a complete secondary barrier capable of containing the cargo for a 15-day period. Ship design and construction standards limit this type of tank to a vapor pressure of less than 0.7 bar.

Type A and B tanks are atmospheric tanks and C is also known as cryogenic pressure vessels. Type C is independent of the ship's hull and not essential for maintaining hull strength and integrity of the ship as well as not the most efficient use of space.

Types of LNG Storage Tank

Kinds	Independent Type A	Independent Type B	Independent Type C	Membrane
SHAPE				
Design Pressure	< 0.07 MPa (Square Type)	< 0.07 MPa (Square Type)	High Pressure (10 bar)	≤ 0.025 MPa
Secondary Barrier	Totally	Partially	Not required	Totally
LNG Track Record	X	O	O	O
Gas Fuelled Ship Track Record	X	Under review	O	X
Load Efficiency	Good	Spherical: Bad Square: Good	Cylinder Type: Bad	Good
Others	High Cost	Trust	Trust	Sloshing

For the same ship size, Membrane type tank is able to store more LNG than other types and is widely used as the storage tank for LNG carriers. However, there is possibility of pressure increase from inside due to gasification and is relatively weak to sloshing problem. Therefore, it has limitations to be used as the fuel storage tank for LNG fuelled ships.

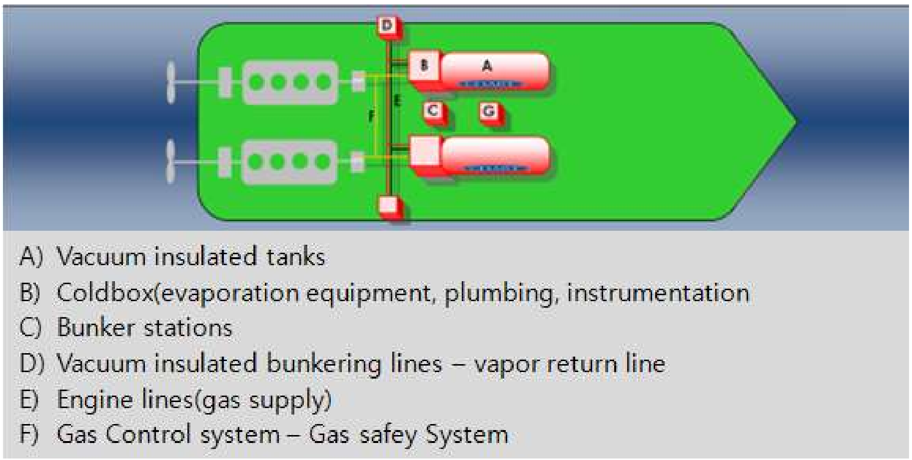
A type and B type, which have better space utilization than C type, can solve the sloshing problem after reinforcement of the inner side. However, the pressure of tank inside is not high enough to solve the problem of BOG without addition measure.

C Type is designed based on a pressure vessel concept, thus best solve both problems of sloshing and BOG and has the advantage of easy installation and easy maintenance. However, due to its high weight and low space utilization, C Type tank still has some limitation for large volume LNG fuel storage and long distance voyage.

Recent Development of LNG Fuel Tank

LNG Fuel tanks for ships are developed, mostly based on Type C tank. The following chart shows a typical LNG ship fuel installation designed by CHART Industries Corporation.

LNG Fuel Tank Configuration



Source: Chart Industrues, Inc.

It consist a tank with integrated 'coldbox' that is an air-tight enclosure of all the plumbing, valves, evaporation equipment and instrumentation attached to the tank. Such configuration is that the gas-hazardous space is limited to the 'Coldbox', instead of the whole tank compartment. Insulation of the tank is of high importance to minimize heat leak into the tank, warming up the LNG. The more heat leak occurs, the faster the pressure will rise and the shorter the tank holding time (time before the safety valve opens) becomes.

'Type C' LNG fuel Tank

4. LNG Bunkering

1) The Importance of Bunkering

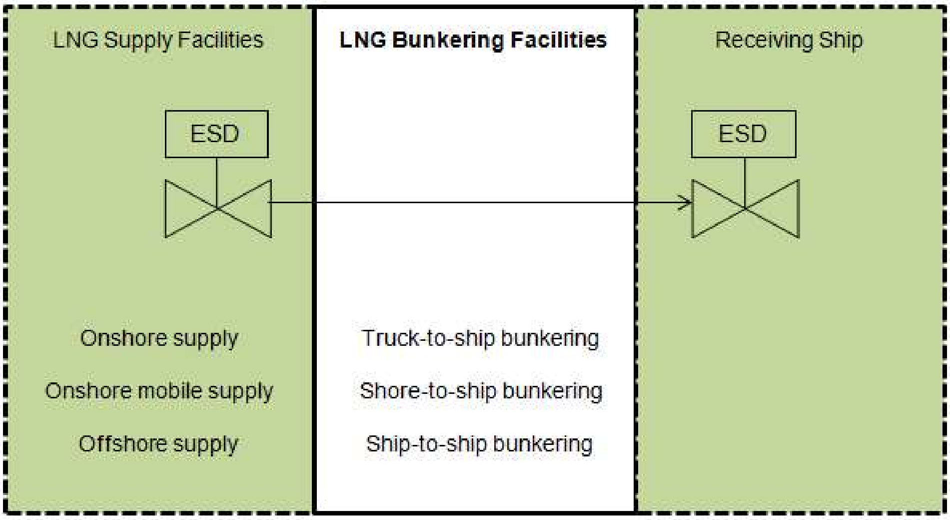
Bunkering is the process of transferring fuel from a supplier to a consumer. In the context of this document, bunkering relates to the transfer of LNG from a supply installation to a receiving vessel. The supplied LNG has the sole purpose of being used as a marine fuel.

The bunkering infrastructure is important for the development of LNG fuelled ships. Lack of bunkering infrastructure, the normal operation of LNG fuelled ships will be interfered. One of the reasons that Norway succeeds in promoting LNG fuelled ships is because they have been able to provide refueling infrastructure.

2) LNG Bunkering Systems

LNG bunkering systems can be largely divided into three parts, LNG supply facilities, LNG bunkering facilities and LNG fuelled ship as the receiving vessel. In order to promote LNG fuelled ships, both of the supply facilities and the bunkering facilities should be developed together.

Bunkering Scenarios



Source: Guidelines for systems and installations for supply of LNG as fuel to ships (ISO TC67 WG10)

3) LNG Supply Facilities: Onshore Vs Offshore

LNG supply can be from onshore LNG facilities or from bunker vessels, typically a barge or a small ship located on the offshore. What kind of LNG supply method should be developed in a port depends on whether the source of LNG is local to the port or must come from some distance. Safety considerations, such as simultaneous cargo operations and other activities and hazards that occur during bunkering, affect bunkering method.

Comparison between onshore and offshore bunkering

	Onshore	**Offshore**
Feature	LNG station installed onshore. Use truck or pipelines to supply LNG to the ships.	Use LNG shuttle ships to supply LNG from the onshore or offshore floating terminal to the ships
Strength	➢ Suitable for medium and small scale LNG bunkering ➢ Easy refueling in port ➢ Short waiting time ➢ Bunkering and deliveries can occur Simultaneous	➢ Suitable for large scale LNG bunkering ➢ No need for port facility conversion and risk diversification effect ➢ Easy complex function: LNG terminal capabilities and LNG power plant
Weakness	➢ High land cost (land purchase or landfill) ➢ Limited application for other functions such as electricity generation	➢ Bunkering shuttles are required ➢ Dependence on marine environment

Source: KIOST

4) LNG Bunkering Facilities: Four Methods

There are four different LNG bunkering methods that either have been commonly used or have been idealized

Truck-to-Ship

It is the most common method used to support the LNG fueled ship network. It is the transfer of LNG from a truck's storage tank to a vessel moored to the dock or jetty. A typical LNG tank truck can carry 13,000 gallons of LNG and transfer a complete load in approximately one hour. Truck-to-Ship bunkering offers great flexibility, however, capacity and supply security can be limited.

Shore-to-Ship

LNG is transferred from a fixed storage tank onshore through a cryogenic pipeline with a flexible end piece or hose to a vessel moored to a nearby dock or jetty. These facilities have large onsite storage and could be capable of performing bunkering of larger volumes. But, Shore-to-Ship must be sited at a fixed location, relatively close to the dock or jetty.

Ship-to-Ship

It is the transfer of LNG from one vessel or barge, with LNG as cargo, to another vessel for use as fuel. Ship-to-Ship offers a wide range of flexibility in location bunkering, and flexibility on quantity and transfer rate.

Ship–to-Ship Bunkering in the Port of Stockholm

Sweden is the pioneer of Ship-to-Ship bunkering. The Swedish company AGA has been operating the first LNG bunkering ship "Seagas" to refuel LNG fuelled ferries since March, 2013. The "Seagas" bunkers approximately 40,000 gallons of LNG in one hour to the ferry Viking Grace on a daily basis (Ref. /6/).

The First LNG Bunkering Ship "Seagas"

Source: Sirius Shipping

Portable tanks

They can be used as portable fuel storage. They can be driven or lifted on and off a vessel for refueling. The quantity transferred is flexible and dependent on the number of portable tanks transferred. A 40-foot (ISO-scale) intermodal portable tank can hold approximately 13,000 gallons of LNG.

Advantages and Disadvantages of the Different Bunkering Solutions

Picture			
Method	**Ship-to-Ship**	**Truck-to-ship**	**Shore-to-Ship**

	Ship-to-Ship	**Truck-to-ship**	**Shore-to-Ship**
Advantages	Flexibility	Flexibility	Availability
	High loading rate	Low costs (investment & operation)	Large bunkering volumes are possible
	Large bunkering volumes are possible		Quick bunkering procedures are possible
	Bunkering at sea (enlarged market)		
Disadvantages	Maneuverability in port basins	Small quantities	Fixed to certain quays
	High costs (investment & operation)	Low loading rate	Occupy terminal space

5) Development of LNG Bunkering Facilities

According to statistics by the WPCI (World Ports Climates Initiative), 14 ports in the world are able to provide LNG bunkering services now, Most of these LNG capable ports locate in Europe. This is largely due to the supportive policy that EU adopted. At present, EU provides a LNG bunkering service at 11 ports, and more than 20 LNG bunker facilities are going to be built in the near future.

Existing and Upcoming Bunkering Locations

Source: DNV-GL

Through its Trans-European Transport Network (TEN-T), the EU is providing significant funding for a wide range of schemes that support the development of cleaner, more efficient road, rail, air and water networks. TEN-T funding supports construction of LNG infrastructure, as well as for stakeholder platforms and research projects.

Europe

LNG is currently available as a bunker fuel for maritime and inland shipping at the WPCI ports of Antwerp, Amsterdam, Rotterdam, Zeebrugge and Stockholm. In addition, LNG can be bunkered at several Norwegian ports.

Norway has historically been involved in LNG bunker transfers to ships and currently operates the largest small scale LNG production and distribution network. Small scale LNG production and regasification facilities in Norway that facilitate the distribution of LNG to bunkering stations, ships or trucks include those located at Tjeldbergodden, Kollsnes, Karmøy, Øra and Risavika, with Statoil, Skangass and Shell (Gasnor) being the main developers.

Storage and bunkering stations already in operation include Naturgass Møre in Alesund, Sunndalsøra (Gasnor-Shell), Høyanger, Mosjøen, Ågotness Coast Centre Base (CCB), Halhjem terminal, and Florø (Saga Fjordbase). Many of these have already been used for truck-to-ship or shore-to-ship LNG bunker operations.

LNG Terminal in Norway


at Mosjøen


at Bergen


at Florø


at Halhjem

New plans for bunkering infrastructures are under development in light of the potential for growing demand for larger volumes of LNG bunkers.

Ports in Europe where major development projects are underway to set up LNG bunkering facilities and infrastructure for oceangoing vessels are as follows:

- Hamburg and Brunsbüttel, Germany
- Rotterdam, Netherlands
- Antwerp, Zeebrugge, Belgium
- Gothenburg, Stockholm, Sweden
- Ports in Norway

LNG in Port of Gothenburg(Sweden)

To make it easier for shipping, industry and heavy transport to gain access to natural gas, an LNG terminal will be built in Gothenburg. Behind the investment are Swedegas and Vopak in collaboration with the Port of Gothenburg. The terminal will be built beside Vopak's facility at the Skarvik Harbour and will become operational in 2015.

The LNG terminal supports Gothenburg's vision of being a sustainable city. For the Port of Gothenburg, it means development of the energy business and to offer customers a fuel that could heighten their competitiveness even further.

On completion, the total capacity will be approximately 30,000 m3. The terminal will have vacuum-insulated, pressurized storage tanks and a full containment tank, which comprises an inner stainless steel tank for the cooled liquid (LNG) and an outer reinforced concrete shell. Processing equipment is also being built in order to regasify the liquefied natural gas, allowing it to be distributed to the nearby gas transmission grid.

Port of Gothenburg is investing in an infrastructure and working to ensure that rules and regulations ar e in place for safe handling. Offering liquefied natural gas to the shipping industry is one of the top pri orities at the port, and the aim is to be able to offer LNG as part of a cohesive logistics chain.

Source: WPCI

North America

LNG bunker facilities are likely to be developed very quickly in the US and possibly in Canada in line with expected calls for competitive clean fuel linked to cheaper shale gas. LNG bunkering facilities have been discussed in New York, Los Angeles, Seattle, Vancouver, Tacoma and the Great Lakes.

Asia

In Asia, LNG is more costly than in North America or Europe. In addition, there is no ECAs located in Asia that mandate low sulfur fuel. These are some of the reasons there has been less development in Asia for the use of LNG as a marine fuel. However, as part of the worldwide effort to reduce harmful air emissions from vessels, some nations in Asia are carrying out studies and developing plans for setting up LNG bunkering facilities and the appropriate regulatory framework.

Singapore's Maritime and Port Authority (MPA) is in the forefront of the efforts to set up LNG bunkering facilities in Asia. It has announced that it plans to offer LNG bunkering in 2015. Singapore is currently one of the world's largest bunkering ports for oil fuels and it is located on major shipping lanes, so it is well positioned to be a major center for LNG bunkering. Initial efforts are focused on ship-to-ship LNG bunkering from small bunker vessels that can obtain LNG from the new LNG terminal in Singapore. Singapore is actively carrying out studies on the required regulatory framework and technical requirements for LNG bunkering and the requirements for personnel training, safety zones and safety standards. It is expected regulations and standards will be issued in the next few years

Singapore LNG Terminal

Source: Singapore LNG Corporation

Efforts are also taking place in China to switch to natural gas as a fuel for the transportation chain, including shipping. Current initiatives mainly involve inland navigation vessels, one example of which is the plan to develop stations to bunker LNG ships navigating the Yangtze River. Ports like Shanghai, Nanjing and Wuhan long the Yangtze River are expected to be the pioneers in China.

The Chinese Ministry of Transport (MOT)'s Plan

(By 2015) 2% of the domestic inland fleet operating on LNG dual fuel vessels
(By 2020) 5~10% operating on DF vessels
(By 2030) 200~500 vessels solely fuelled by LNG

Source: Xinhua News

Korea's major gas company, Korea Gas Corporation (KOGAS), has been facilitating LNG bunkering since 2013 via truck-to-ship operations involving the Incheon Port Authority ferry Econuri. KOGAS is also studying the possibility to construct LNG bunkering facilities in Busan. It is also in discussion with China to supply LNG as a marine fuel for ferries operating on the Korea-China routes.

In the case of Japan, NYK shows strong interest on providing LNG as a marine fuel after its construction of the economy's first dual-fuel tug boat that can run on either HFO or LNG.

5. The Development of LNG Fuelled Ships

1) History

The first ship powered by LNG on earth is the Danish fishing boat, Frank FN282. The vessel is equipped with a 2-cylinder, 90/100hp, Alpha Diesel type 342 engine, custom ized for 'dual fuel' operation, with oil injection as the pilot fuel igniting the gas charge.

The first ferry run on LNG is ‘Glutra’ which came into service in Norway in 2000. The engines of this vessel are pure gas Otto cycle engines. The Mitsubishi GS12R-PTK ultra lean burn natural gas engines in V12 configuration attain a power output of 675 kW at 1500 rpm.

It has an overall length of 94.8m, a beam moulded of 15.7m and a depth moulded to main deck of 5.15m. The ferry can carry 300 passengers and 96 passengers’ cars or 8 trailers and 42 passenger cars, a standard for Norwegian ferries

Frank FN282

Source: dieselduck

Glutra

Source: DNV-GL

Since Glutra’s first sailing, several small LNG fuelled ships were built and operated in coastal areas of Norway. In 2013, the Fjordline Cruise ship-like ferry Stavangerfjord(installed with a Rolls Royce gas engine) started operating between Denmark and Norway, which is the first inter-country, operated LNG fuelled ship.

Norway, the Leader of LNG Fuelled Ships

For a single country, Norway is the market leader with biggest 'LNG capable' fleet globally. To use natural gas as fuel for ships has been the Norwegian transportation authorities' vision for a long time. Norway is a very big producer of natural gas, this vision was founded on the environmental benefits as well as the will to develop Norwegian gas technology.

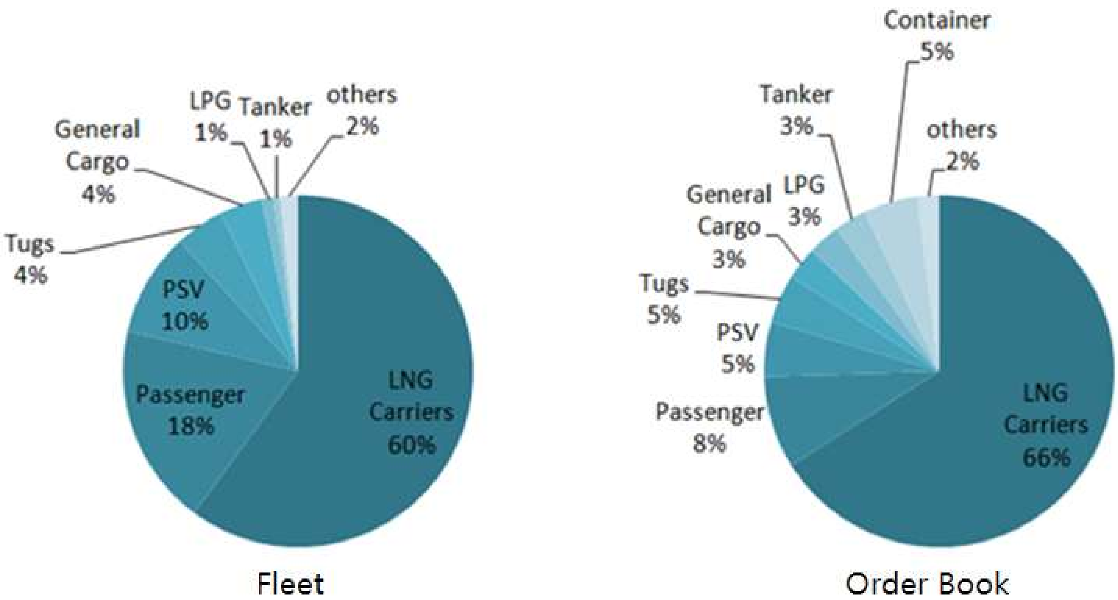
Early in 1995, the Norwegian Storting decided to fund a test project for ferries fuelled with natural gas. In 2000, Glutra, the first roro/passenger ferry powered by LNG in the world entered service. Base on the experiences on Glutra, the Norwegian class society DNV(Det Norske Veritas) formed its draft regulations for ferries powered by natural gas. These regulations are now one of guidelines that the industry most frequently refers to. In order to promote using LNG as a marine fuel, the Norwegian government provided funding for investment in LNG technology. It also imposed a NOx tax in 2007.

In response to the NOx tax from the Norwegian Government, the Confederation of Norwegian Enterprise established a private NOx fund. The Fund supports NOX reducing measures in the affiliated enterprises. The NOX Fund has granted support to almost 600 applications reducing more than 28,500 tons of NOX from 2008 until early 2015. The fund is now experiencing an increasing trend of applications for LNG fuelled ships and up to this date, the NOX Fund has granted support to 43 LNG fuelled ships and the number is expected to increase in the future. The support rate for LNG fuelled new-buildings and conversions are up to 80% of the investment cost.

2) Current Status

Nowadays, LNG is no longer an option for smaller ships operating in coastal areas only, but also being adopted by many ocean-going commercial ships. According to Clarkson's statist ics, there are 178 ships that are either LNG fuelled or capable of running on LNG wo rldwide as of March, 2015. LNG carriers count for 62% of this fleet; other ship types include passenger/car ferries, PSVs, general cargo vessels and etc.

Current Fleet and Order Boom of LNG Capable Ships



Source: Clarkson

Current order book LNG capable ships totals at 200 units, with LNG carriers taking the biggest portion of 67% while a broader range of ship types take the rest portion. More container ships and tankers are under construction, which is a meaningful signal of expansion of LNG as a marine fuel.

LNG Capable Ships Ordered Since Sept. 2014

Ship Type	Yard	Contract Date	Size (GT)	Owner
Fully Cellular Container	Yangzhou Guoyu	Sep-14		Guoyu Nordic Shpg
Fully Cellular Container	Yangzhou Guoyu	Sep-14		Guoyu Nordic Shpg
TUG	Dubai Drydocks	Nov-14	300	
TUG	Dubai Drydocks	Nov-14	300	
TUG	Dubai Drydocks	Nov-14	300	
TUG	Dubai Drydocks	Nov-14	300	
TUG	Dubai Drydocks	Nov-14	300	
TUG	Dubai Drydocks	Nov-14	300	
TUG	Dubai Drydocks	Nov-14	300	
TUG	Dubai Drydocks	Nov-14	300	
TUG	Dubai Drydocks	Nov-14	300	
Asphalt & Bitumen Carrier	Besiktas Shipyard	Nov-14		Le Groupe Desgagnes
Asphalt & Bitumen Carrier	Besiktas Shipyard	Nov-14		Le Groupe Desgagnes
Pass./Car Ferry	Guangzhou SY Intl	Nov-14	35000	Rederi AB Gotland
Pass./Car Ferry	Sedef Gemi (Tuzla)	Nov-14	10000	Seaspan Marine
Pass./Car Ferry	Sedef Gemi (Tuzla)	Nov-14	10000	Seaspan Marine
Fully Cellular Container	Yangzhou Guoyu	Jan-15		Guoyu Nordic Shpg
Fully Cellular Container	Yangzhou Guoyu	Jan-15		Guoyu Nordic Shpg
Pass./Car Ferry	Ada Shipyard	Jan-15	2000	Fjord1 AS
Pass./Car Ferry	Ada Shipyard	Jan-15	2000	Fjord1 AS

Source: Clarkson

Most of LNG capable fleet and order book is owned by the Europeans. North America also has a relative big presence in the sector. For Asian economies, China, Japan and Korea are the pioneers in the region.

Recently, large ocean-going commercial ships begin to take LNG as a fuel for option. In April, 2015, United Arab Shipping Company (UASC) named the industry's first LNG-ready ultra-large container vessel M.V. 'Barzan'. This ship is built in the Korean shipyard, Hyundai Samho Heavy Industries (HSHI) with a loading capacity of 18,800TEU.

The M.V. 'Barzan'

Source: UASC

Despite limited numbers of fleet and order book, investment in LNG fuelled tonnage is increasing fast and more and more infrastructure projects are planned or proposed along the main shipping lanes. In its recent publication "In Focus – LNG As Ship Fuel", DNV GL expects LNG to grow even more rapidly over the next five to ten years

3) Barriers to LNG Fuelled ship

Technologies of LNG fuelled ships are all proven and commercially available which supports the commercialization of using LNG as a marine fuel. Quite a lot of projects either new-building or conversion are carried out. However, there remain other barriers.

Firstly, out of presence of a unified international regulation framework is on factor limiting the widespread use of LNG as a marine fuel. IMO and ISO are working hard on regulation and standard setting to remove this barrier.

Secondly, the limited LNG bunkering network remains as a key concern. For most commercial ships to use LNG as a fuel, availability of LNG bunkering at both port of call and in seawater should be secured. Recently many ports are investing in infrastructure, especially in Europe. Besides, the technologies of dual fuel system also provide a solution in the short run for owner to flexibly switch between gas and oil for fuel depending on the availability and price. But, things should be further improved.

Thirdly, large capital investment is required for LNG fuelled ships. More complicated propulsion systems, low-temperature endurable equipments, space occupancy by the LNG fuel tank are the elements increasing construction costs of LNG fuelled ships.

6. Conclusion

Today LNG is emerging as the most promise marine fuel largely due to its cleanness, abundance, technology readiness and economically affordability.

The biggest motivation of using LNG as a marine fuel lies in environmental concern. Ship emissions affect the local air quality especially when sailing close to shore. Emissions of SOx from shipping represent about 60% of global transport SOx emissions. Emissions of NOx shipping account for about 15% of global anthropogenic NOx emissions. Besides, international shipping accounts for approximately 2.2% and 2.1% of global CO2 and GHG emissions in 2012, respectively.

A heightened focus on reducing emissions from shipping is dressed to minimize the impact of air pollution on the environment to protect human health and improve local air quality in port areas and neighboring residential districts. LNG as a marine fuel can help significantly reduce NOx, SOx and particulate emissions by 85-100% in comparison with HFO. It also helps to reduce GHG emission by around 20%. The use of natural gas as a marine fuel allows compliance with all current and known future emission requirements.

Worldwide reserves of natural gas are thought to be significantly higher than for petroleum and the International Energy Agency estimates there is sufficient supply for 250 years of consumption. The abundance of this resource provides a sound base for extensive usage of LNG as a marine fuel. In natural gas rich economies, for example Norway, conversion from traditional oil fuel into LNG together with LNG bunkering facilities are largely supported by the government. Major ports like Rotterdam and Singapore, LNG bunkering is already available or will be provided soon. The on-going development of bunkering infrastructures also will make LNG more attractive as a marine fuel.

LNG as fuel is now a proven and commercially available solution. All of the technologies are ready to commercial use, including tankers for fuel storage, dual fuel and pure gas engines in power ranges that meet the needs of many types of coastal and deep sea vessels. Development of engine technologies and onboard fuel storage systems is also continuing.

SWOT Analysis: The LNG Fuel Option

Strengths	Weaknesses
➢ Fully compliant with NOx, SOx and PM emissions legislation. ➢ High level of GHG (carbon dioxide) reductions (approximately 20%). ➢ Proven technology. ➢ Minimum additional OPEX. ➢ Potential price differential with traditional marine fuels.	➢ High capital investment costs. ➢ Technically complex. ➢ Widespread suitability for deep-sea cargo ship types still uncertain. ➢ Operational issues. ➢ Delivered cost of LNG fuel still uncertain. ➢ Limited bunkering network at present.
Opportunities	**Threats**
➢ Growth in Emission Control Areas (ECAs). Many potential additional areas, e.g. the Med, Australia and Hong Kong. ➢ Established LNG supply chain. ➢ Increasingly seen by many key stakeholders as the main alternative. ➢ Government support, e.g. Norway. ➢ Support from key ports in developing LNG bunkering networks, methods and procedures. ➢ The regulatory difficulties and safety concerns are being effectively addressed. ➢ Public (customer) perception.	➢ The current bunker price environment: This has eroded the potential beneficial price differential with traditional marine bunker fuels. ➢ Limited availability of LNG for use as marine fuel. ➢ Effectiveness/popularity of alternative solutions. ➢ Delayed implementation of MARPOL Annex VI ➢ Usually conservative nature of ship owners. ➢ Securing finance (weak shipping markets). ➢ Residual value concern.

Source: Clarkson

The challenges for natural gas lay in volatility of energy price especially the price parity between oil and gas. Bunkering infrastructures are improving but not enough yet. The unified international regulatory framework should also be built for safety purpose. Ongoing collaboration in international organizations like IMO is believed to be essential to clearing the regulatory path.

Despite with the weakness of LNG fuelled ships currently, marine sector shows a strong interest on it. Applications on coastal ships are expanding from Europe to North America and Asia. Quite a lot of new-building and conversion projects of sea-going ships of large size are undergoing. Successful launch of these ships will give more confidence to the sector for LNG as an alternative fuel in the near future.

As for APEC economies, knowledge sharing and collaboration are important to achieve greener port and better environment through LNG such as co-work on standards, mutual assistance in infrastructure and etc. Adopting LNG could also lead to a wide range of industrial and service opportunities. Business opportunities emerge in shipbuilding, ship design, bunkering infrastructure construction, related equipment manufacturing and training services. Supportive industrial policies can be developed to grasp the opportunities and enlarge social welfare in APEC region.

ACRONYMS

CEN	The European Committee for Standardization
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
FERC	Federal Energy Regulation Commission
GHG	Green House Gas
IFG Code	International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels
IGC Code	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IMO	International Maritime Organization
ISO	International Organization for Standardization
MARPOL	International Convention for the Prevention of Marine Pollution from Ships
MBM	Market Based Measure
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
NFPA	National Fire Protection Association
NO_x	Nitrous Oxides
OCIMF	Oil Companies International Marine Forum
ODS	Ozone Depleting Substances
PM	Particulate Matter
rpm	Revolution per minute
SEEMP	Ship Energy Efficiency Management Plan
SIGTTO	Society of International Gas Tanker & Terminal Operator
SO_x	Sulphur Oxides

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