

LPG for Marine Engines

The Marine Alternative Fuel

**Commercial, Passenger, Offshore Boats/Ships,
Recreational Crafts and Other Boats**



Innovation & Technology

The World LPG Association

The WLPGA was established in 1987 in Dublin, Ireland, under the initial name of The World LPG Forum.

It unites the broad interests of the vast worldwide LPG industry in one organisation. It was granted Category II Consultative Status with the United Nations Economic and Social Council in 1989.

The WLPGA exists to provide representation of LPG use through leadership of the industry worldwide.

Foreword

A great man once said “To know something and not do it is the same as not knowing it at all”. What we take for granted today was impossible just a few years ago. The quick adaptation of LPG as a fuel in the marine sector would be a great step forward for the environment, cleaner air and cleaner water. With its lower cost of implementation and its readily available infrastructure, LPG, an exceptional energy, has significant advantages over other alternative fuels. As a pioneer in LPG marine applications, I see as my maritime mission to assist in the rapid adaptation of this exceptional solution changing the world for the better.

I believe this report, thanks to the World LPG Association, creates that ripple in the water that can carry across the oceans.

Capt. Bernardo Herzer

Acknowledgements

This report has been developed by the Innovation & Technology Network of WLPGA.

There could be views expressed in this document that are not necessarily shared by all contributors.

Key contributors:

George Nikolaou, NaTco/Liquid Gas Europe

Makoto Arahata, Japan LPG Association

Rubens Basaglia, X-Tech

Niels Frederiksen, Hexagon Ragasco

Peter Hadjipateras, Dorian LPG

Tatsuya Hamaguchi, Astomos

Warring Neilsen, Elgas

Tucker Perkins, PERC

Øyvind Solem, BW LPG

David Tyler, WLPGA

Cameron Ure, Elgas

Nikos Xydias from WLPGA coordinated this project.

LPG for Marine Engines

The Marine Alternative Fuel

**Commercial, Passenger, Offshore Vessels,
Recreational Crafts and Other Boats**

Contents

Page

Foreword	1
Chapter One	6
Introduction.....	6
Chapter Two	7
Executive Summary	7
2.1. Key Messages - Fact Sheet	10
2.2. Key Messages – Roadmap.....	15
2.3. Key Messages – Recommendations	16
Chapter Three	17
Fact Sheet	17
3.1. The Product – LPG as Marine Engine Fuel	17
3.1.1. Production.....	17
3.1.2. Worldwide Production.....	18
3.1.3. Transportation	19
3.1.4. Bunkering.....	21
3.1.5. Pricing	23
3.1.6. LPG propulsion – Fuel Cost Benefits.....	24
3.1.7. Environmental, emissions to air and water	25
3.1.8. Order book	27
3.1.9. Main Advantages of LPG as Marine Fuel	28
3.1.10. LPG Propulsion Sustainability in Summary	29
3.2. Marine Engine Technologies	31
3.2.1. High-speed engines (>1000rpm)	32
3.2.2. Medium-speed engines (300-1000rpm)	33
3.2.3. Low speed engines(<300rpm).....	34
3.2.4. Electric Motors (with LPG power generators)	39
3.2.5. LPG Range extenders.....	41
3.2.6. LPG Reformer	42
3.3. Marine LPG Engine Types.....	43
3.3.1. Otto petrol/LPG bi-fuel engine.....	44
3.3.2. Otto LPG Mono Fuel engine.....	44
3.3.3. Dual-fuel Diesel/LPG engine (diesel engine with direct LPG injection)	44
3.3.4. Diesel – ignited LPG engine.....	47
3.3.5. Gas fuel or Tri-Fuel Propulsion.....	47
3.3.6. LPG Gas turbine.....	48
3.3.7. LPG Outboard engine, mono fuel or bi-fuel.....	50
3.4. Ship propulsion.....	53
3.4.1. Direct Drive	54
3.4.2. Hybrid, Parallel	54
3.4.3. Hybrid, Serial	59
3.4.4. Electric with “Range Extender” engine.....	61
3.4.5. Tri-Fuel Diesel Electric Propulsion (TFDE) Over Diesel Engine Propulsion	61
3.4.6. Outboard/Inboard engines	63
3.4.7. Ethane powered ship engine	65
3.4.8. Engines running on LPG could be converted to ammonia.....	66
3.5. Marine Engine Application Segments.....	68
3.5.1. Ship Segments Overview	68

3.5.2.	Commercial Vessels.....	69
3.5.2.1.	Cargo ships.....	69
3.5.2.1.1.	Large ocean-going ships-VLGCs	69
3.5.2.1.2.	Tankers	75
3.5.2.1.3.	Bulk carriers.....	75
3.5.2.1.4.	Containerships.....	76
3.5.3.	Fishing Boat/Ships	77
3.5.4.	Passenger Vessels.....	78
3.5.4.1.	Cruise ships.....	78
3.5.4.2.	Ferries.....	79
3.5.4.3.	Yachts	81
3.5.5.	Offshore Service Boats	81
3.5.5.1.	Exploration and Production	82
3.5.5.1.1.	Seismic Vessels	82
3.5.5.1.2.	Drill Ships.....	82
3.5.5.1.3.	Cable/Pipe Layers.....	83
3.5.5.2.	Towboats	83
3.5.5.3.	Supply + Service Boats.....	83
3.5.5.3.1.	Platform Supply Vessel.....	83
3.5.5.3.2.	Anchor Handling Vessels	84
3.5.5.3.3.	Safety Standby Vessels.....	84
3.5.5.3.4.	Installation vessels	84
3.5.6.	Recreational Crafts and Other Boats.....	85
3.5.6.1.	Rib and Speed Boats.....	85
3.5.6.2.	House Boats	86
3.5.7.	Naval Vessels.....	87
3.5.7.1.	Military	87
3.5.7.2.	Rescue /Patrol.....	87
3.5.8.	Others	88
3.5.8.1.	Dredgers	88
3.5.8.2.	Tugs- Work Boats	89
3.5.8.3.	Ice Breakers	89
3.6.	Conversions and Retrofitting	90
3.7.	LPG vs LNG	91
3.8.	Bunkering Methods	101
3.9.	Main Players.....	103
3.10.	Regulatory Framework	103
3.10.1.	Regulatory Framework in Recreational Craft Sector.....	104
3.10.2.	Regulatory Framework in Commercial Shipping Sector	106
3.11.	Safety	117
3.12.	Training	119
3.13.	Quality of Fuel	119
3.14.	Environmental Aspects	120
3.15.	Main Stakeholders.....	123
3.15.1.	Design Offices	124
3.15.2.	Marine engine manufacturers	125
3.15.3.	Shipyard.....	127
3.15.4.	Classification Societies.....	127
3.15.5.	Ship owners, Cargo owners, Ship operators.....	127
3.15.6.	LPG Distribution Companies and Associations	129
3.15.7.	Policy Makers, Governments, Regulators.....	129

3.15.8. Other Societies	129
3.16. Engagement of Main Stakeholders	130
3.17. Market Status	130
Chapter Four	132
Roadmap.....	132
4.1 Market Outlook on Technology Developments	132
4.2 Market Outlook on Regions	133
4.3 Barriers to Growth.....	134
4.3.1 Customer economics: investment for ship owners and economics for fleet operators	134
4.3.2 Positioning LPG to policymakers and decision makers: Need to be on a level playing field with other alternative fuels.....	135
4.3.3 Technology Development of new engines: In the recreational sector, there is a slow rate with limited growth. In big vessels, there are few early development projects under development	135
4.3.4 Commercialisation of new engines: Sales, servicing and maintenance networks are required	136
4.3.5 LPG Awareness/Perception for decision makers: Shared Vision with LPG marine engines, Equipment and Engine manufacturers, Naval Architects, Ship owners, Ship operators and All Types of Users as a Preferred Option	136
4.3.6 Bunkering Infrastructure: Development of bunkering infrastructure uncertainty of LPG supply and bunker price makes it difficult for a ship-owner to invest on LPG-fuelled ship.....	136
4.4 Market Potential.....	138
4.4.1 Target Regions.....	139
4.4.2 Target Boat/Ship Segments	141
Chapter Five	143
Recommendations	143
5.1. Customer Economics- investment for ship owners and economics for fleet operators the Greatest.....	143
5.2. Positioning LPG to policymakers and decision makers: Need to be on a level playing field with other	144
5.3. Technology Development of new engines and ship designs: Big vessels - few early projects under development. Recreational sector - slow rate with limited growth.....	144
5.4. Commercialisation & Getting Products to Market	145
5.5. LPG awareness for decision makers: Shared vision with marine engine manufacturers, naval Architects, designers, ship owners, ship operators and traders need to be considered	145
5.6. Bunkering Infrastructure: Development of bunkering infrastructure, uncertainty of LPG supply and bunker price, a concern for a ship-owner to invest on LPG-fuelled ship	145
Appendices.....	146
Appendix 1	146
Appendix 2	148
Abbreviations	149

Chapter One

Introduction

The aim of this report is to **promote understanding amongst the LPG industry and beyond, of the technical possibilities, applications and market potential of LPG for marine engines**. Ultimately this is to inform the LPG community of the numerous opportunities in the various related segments, of current development in the gaseous fuel market and of actions to take, in order to “pave the way” for take-up in the marine routes.

The report scope includes:

- ▶ A scan of the market for **marine LPG engines** and even more in this case for **marine engines and particularly those gas marine engines**, which after additional development or conversion could use LPG as a fuel.
- ▶ Identification of market characteristics and marine engine applications which are more promising for LPG as a marine fuel.
- ▶ Coverage of commercial and passenger vessels as well as emerging developments in inboards, outboards recreational boats and other crafts.

The main objective, besides giving a bird-eye’s view snapshot of the sector as a whole, is to identify concrete opportunities for the LPG industry.

This report contains:

- ▶ **A ‘fact sheet’** giving an overview of the current marine LPG and other gaseous fuel technologies, main players in the value chain and market status.
- ▶ **A ‘roadmap’** providing stakeholders with different types of boat propulsion systems, exploring the market outlook for each technology and identifying the drivers and barriers for future growth.
- ▶ **Recommendations** targeting stakeholders and association members on how to overcome the barriers for entering the shipping sector and also on maximising the market opportunity in existing smaller waterborne vessels.

Chapter Two

Executive Summary

Global marine propulsion engine revenue market is expected to reach \$12 billion by 2022, growing yearly at around 4.1% from 2016 to 2022¹ and it is expected to witness growth during the forecast period owing to various ongoing government investments in shipbuilding industry and inland waterways.



The increase in production and sales of ships globally, and the rise in international seaborne trade, partly also due to increase in demand for resources such as crude oil, coal, steel, and iron from developing countries, drive the market growth. Over 90% of the world's goods by weight and volume are transported by sea. Offshore exploration and production are expected to grow to from 35% to 45% over the next decade². However, stringent environmental regulations and large capital investment required to set up new manufacturing facilities hamper the market growth. Irrespective of these challenges, rise in usage of inland waterways and advancements in technologies, such as new alternative fuel propulsion engine technologies, are expected to provide various opportunities for these technologies and boost market growth.

Like all other forms of transportation that burn hydrocarbon fuels for energy, marine transportation releases significant volumes of emissions as by-products. Of the two types, air polluting sulphur and nitrogen oxides and particulate matter are dangerous for the environment and human health, while greenhouse gas emissions, such as CO₂ and methane, contribute to climate change.

The use of LPG as an engine fuel is arguably the most commonly accepted alternative fuel in the world today. LPG is readily available globally and is lauded as a clean, energy efficient and portable fuel with an affordable price tag. It's

¹ <https://www.marineinsight.com/shipping-news/marine-propulsion-engine-market-expected-reach-12-billion-2022/>

² <https://www.rolls-royce.com/~media/Files/R/Rolls-Royce/documents/investors/results/presentations-and-briefings/02-introduction-to-marine-tcm92-61444.pdf>

currently sourced mainly from natural gas and oil production activities. However, in the wake of new technologies and techniques, LPG can also be produced from renewable sources.

Today by using LPG can reduce GHG by 17% and this is also fuel that give quite a good safety margin today on newbuilding being compliant for the lifetime of the vessel.

In light of the International Maritime Organization (IMO) mandate, LPG could have a role to play in the process of decarbonising shipping, and it will play a leading role towards IMO's 2050 regulations, which will require further reduction on greenhouse gas emissions by at least 50% until 2050, compared to 2008. Advancements in technologies, such as new alternative fuel propulsion engine technologies, are expected to boost market growth, where the vast majority of engines are diesel, and alternative fuels solutions such as LNG continue their growth, but LPG is starting to get some attention as it stands as a likely alternative among the other gaseous fuels.

However, regarding larger commercial and passenger ships, ship operators, with traditional propulsion plants and fuels, mainly could not meet the new 2020 regulations without installing expensive exhaust equipment or switching to low-sulphur diesel, low-sulphur residual, or other alternative fuels, all of which have an impact on profit. As attention turns to an array of possible solutions, heavy-sulphur fuel oil with scrubbers, distillates, blended fuels and LNG, so as to comply with the IMO's 0.5% global sulphur cap regulation, LPG starts gain more acceptance as a viable solution, as compared to LNG, which is more problematic and expensive to implement.

LPG has made its entry into the marine market segment. **LPG as marine fuel is available now, diesel engines can be retrofitted to burn it, and it will aid a transition to zero-emissions shipping in the future. Currently, LPG is already a preferred marine fuel solution for LPG carriers. Hence, LPG propulsion, starting with the LPG carrier sector, needs to move beyond a niche fuel option, to gain the acceptance in the wider shipping sector that it deserves.** In smaller commercial and recreational vessels with inboard and outboard engines, LPG has been also little exploited up to now, although there are some areas/countries where it has indeed been used.

On 4 November 2020, the world's first LPG-fuelled vessel has set sail. Powered with a MAN dual fuel engine and a Wärtsilä's customised and reliable fuel supply system, the vessel represents a major breakthrough in the search for new ways to reduce marine emissions. After the successful completion of full-scale testing and installation of the systems, the first BW LPG vessel has completed sea and gas trials sailed a transpacific voyage from China to Enterprise



Port in Houston, Texas, on full LPG propulsion. Recently BW LPG announced that three more retrofits have completed sea and gas trials with pioneering LPG propulsion technology. BW LPG noted that the retrofit process emits around 2,060 tons of carbon dioxide, which is 97% lower when compared to ordering a newbuilding with similar technology.

LPG supply surplus is another element in favour, with surpluses ranging from 15 to 27 million tonnes per year³, which are either used or “lost”. The dropped prices of LPG (comparatively also with LNG) driven by the shale gas revolution are also an important driver for market entry. Shipbuilders are already considering vessel designs that use LPG as propulsion fuel.

There is no reason why LPG cannot be used in all sizes of vessels from the largest of ocean-going ships, down to the smaller boats with inboard or outboard engines. LPG can play a major role in this changing environment and re-establish itself in the position that it deserves as an ideal alternative clean marine fuel.

LPG could also act as a bridging fuel to ammonia, as the materials used for LPG tanks and systems are, in most cases, suitable for ammonia. With advanced planning, the adjustments needed for a switch to ammonia from LPG could also be minimised.

Coordinated action from all related stakeholders is key to address the identified specific issues that hinder development and release further the market potential.

³ <https://www.wlpga.org/wp-content/uploads/2019/12/WLPGA-Annual-Report-2019.pdf>

2.1. Key Messages - Fact Sheet

LPG when used as an engine fuel has numerous advantages and a largely untapped potential for marine engines.

- ▶ The use of LPG as an engine fuel is one of the largest and fastest ones growing globally. The properties of LPG and namely its low emissions and its virtually zero particulate emissions, can have an immediate positive impact on air quality.
- ▶ It can also contribute to a 15% reduction in the EEDI (Energy Efficiency Design Index) of new buildings. Engine technology is commercially available for 2-stroke engines, while 4-stroke engines have been used for power generation on land and can be marinised. LPG is also easier to handle than LNG, as cryogenic materials are not required for the fuel tanks. This also results in lower investment costs for such a system.
- ▶ LPG is a viable alternative gaseous fuel for all sizes and types of boats and ships. It is true that the alternative fuels industry has grown dramatically for both liquid and gaseous fuels, but for LPG, although it is relatively easier and more economical to set it up on a vessel compared to LNG, the push remains still limited so far. Only recently, the shipping industry and more particularly the bunkering sector, is considering a bigger role for LPG as a shipping fuel for the years to come.
- ▶ The bunkering infrastructure for natural gas is not mature, whereas for LPG there is already considerable existing infrastructure available around the world that can be used, storage facilities, export terminals, coastal refineries with loading/unloading facilities etc.
- ▶ For LPG carriers, there are even more benefits to use LPG as fuel and in doing so save bunkering time.
- ▶ Some ship owners and manufacturers have already embraced LPG, and especially so with LPG prices being very attractive.



The marine propulsion engine market is expected to witness robust growth during the forecast period owing to various ongoing government investments and new regulations in the shipbuilding industry and inland waterways.

- ▶ It is true that today, the availability of large LPG fuelled engines is limited. MAN Energy Solutions developed, and is commercialising, LPG burning engine to two-stroke dual-fuel line-up and GE's combined gas, electric and steam turbines (COGES). However, variants of large engines and propulsion configurations fuelled by natural gas have been developed, which makes it easier the way for further development of such engines to run on LPG.
- ▶ Due to advancement in technology, diesel or alternative fuel engines and gas turbines have attained greater market penetration.
- ▶ Small inboard and outboard engines are almost exclusively targets for LPG, either as conversions similar to Autogas vehicles, or as OEM models as those of Propel and recently also of Tohatsu, Mercury and Yamaha.
- ▶ Electric hybrids as a marine propulsion technology, have been used for many years, and recently have seen their growth as a solution to improve efficiency, reliability and adjustability of the whole powertrain systems of most types of ships and boats.

The marine engines and propulsion system technologies segment can be divided into petrol, diesel, LPG, LNG, and other propulsion system technologies such as gas and steam turbines, hybrids etc. In summary, a categorisation of engines that can use LPG as a fuel, could be:

- ▶ **Spark-ignited “petrol-LPG bi-fuel or LPG only” engines**, first developed for the land-based power industry with simplicity and good overall performance at lowest total emissions as prime requirements. They initially came into the marine industry as engines for outboard and inboard engines.
- ▶ **Diesel gas engines with direct LPG injection** first appeared in the offshore industry where fuel flexibility and very high-power density was of prime attraction. A concept unique in posing no particular requirements to the self-ignition stability of the fuel gas and its diesel operating principle ensuring very complete combustion of the gas fuel but at the cost of higher NOx emissions than other gas engine types. Its use in marine industry is limited.
- ▶ **Diesel-ignited LPG engines** with dual fuel capability originally developed for power plant use where their ability to operate both on liquid and gaseous fuels at high specific power was a particular advantage. They burn LPG and use marine diesel oil as pilot fuel. This is the most promising market, capable of operation on gas and/or HFO, in different applications such as container ships, bulk carriers, ConRo⁴ vessels, and LPG carriers. Development focus was originally on low NOx emissions at high loads, recently also on part load performance and variable speed capability. The diesel-ignited gas/LPG engine was the first type to establish itself in the marine industry and is currently the dominating engine type in this market.
- ▶ **Gas turbines (could run on LPG)**, conventional gas turbines combined with power generator turbines to provide power to the ship’s propeller, a system of ship propulsion known as “split-shaft gas turbine”. The gas turbine drive shaft contains the turbine starter, while the auxiliary pumps drive the different systems. The gas turbine hot exhaust gasses are fed into the power generator turbine. Gas turbine advantages are power density (i.e., high power in a light weight, small footprint), fuel flexibility and highly reliable Dry Low NOx emissions combustion system. They also provide superior availability for diverse military applications, ranging from patrol boats, corvettes, frigates, destroyers and cruisers. Other potential applications include hydrofoils, fast ferries, cruise ships, floating production storage and offloading vessels, offshore platforms, power barges, high-speed yachts and LPG carriers.
- ▶ **Outboard engines “Bi-fuel or LPG only”** have become a marine propulsion alternative in protected lakes and rivers, as well as fish farms, as a replacement of gasoline two and four stroke polluting engines from their exhaust, not to mention also spillages during refuelling, of detrimental effect on the water and aquatic wildlife. In addition, there are also noteworthy running cost benefits. The restrictions on the use of internal combustion engines on many protected areas leave LPG fuelled outboard and inboard engines as the prime alternative.

The marine engine applications and vessel types market could be categorised as follows:

Large commercial ships, cargo ships, large ocean-going ships, very large gas carriers (VLGCs), tankers, bulk carriers, containerships, passenger ships of all types, offshore service vessels, towboats, dredgers, house boats, recreational craft, even military vessels, patrol and rescue boats, and many more, can be a target for the use of LPG with varying attractiveness for each type, benefits and priority.

LPG can compete economically with LNG and probably also with low sulphur fuel oil after the global sulphur cap changes to 0.5% for new builds.

- ▶ Retrofits will be less cost efficient than new builds.
- ▶ The current global production of LPG and its future increase opens up possibilities for LPG as a marine fuel.
- ▶ The spatial distribution of LPG storage facilities favours LPG over LNG, since the development of a bunkering infrastructure remains a barrier.

⁴ Hybrid vessel of a RORO and a container ship

-
- ▶ Market introduction for a non-drop-in fuel, such as LPG, will always be a challenge, but easiest implementation could be in LPG VLGCs, where fuel is already present (or can be bunkered in connection to cargo loading), and where handling of LPG is well known and safely managed, thereby reducing the distribution costs.
 - ▶ LPG has the advantage of more economical implementation and largely available and less costly infrastructure, terminals, supply points. This is particularly important in certain sectors including small tankers, smaller container vessels and ro-ro ships that operate in coastal areas and on inland waterways where LPG supply infrastructure is always in proximity.

Safety issues linked to the use of LPG as a marine fuel must be addressed, but these are no more challenging than for LNG. New technologies as those related to the use of LPG as marine fuel, as well as the use of LPG as a product itself, require competent operators hence adequate training.

- ▶ Training in the specific installation and the handling of the product itself should always be part of any new project.

Modern equipment and advanced technologies call for increased requirements for fuel quality and the same holds true also for LPG.

- ▶ LPG quality can vary significantly from country to country.
- ▶ Although large marine engines are being designed to accommodate varying quality of fuels, smaller ones used in small boats in the recreational sector need high quality engine fuel. For such engines, having the LPG as an acceptable competitive alternative fuel for current gasoline and CNG/LNG fuelled small engines, the right “formula” can be based on the U.S. HD5 standard, but with low Sulphur (% by volume).
- ▶ Granted quality of LPG becomes particularly mandatory for professional and heavy-duty uses and marine outboard engines.

The use of LPG as marine fuel is being discussed at a time when there is great attention on diesel emissions and pressure has been put on the sulphur levels in traditional maritime fuels.

The environmental argument to convert from conventional polluting marine fuels, including diesel and gasoline, to gaseous fuels and LPG is very strong today, both due to regulatory pressures (new IMO emissions limits), and also increasing awareness of the carcinogenic effects of diesel emissions in general. All types of boats found on inland waterways, rivers and lakes where any form of fuel pollution can cause serious consequences to wild life, fish and the local environment become particular targets for LPG. Any spillage of gasoline and diesel will float on water and even the visual impact of it can be disturbing and lasting.

The IMO recent emissions limits imposed on fuels used in the shipping industry and particularly in ECAs (emission control areas), force the industry to look at alternative fuels as a way of complying with the new limits.

- ▶ CO₂ emissions from shipping are double those of aviation.
- ▶ Maritime CO₂ emissions could rise by 75% in the next 15 to 20 years.
- ▶ CO₂ monitoring for all ships will establish a base line for future reduction.
- ▶ EU leading the way and a global system is under negotiation within the IMO.
- ▶ From 2018, large ships using EU ports required to report verified annual emissions.
- ▶ Stakeholder pressure to manage environmental and climate risks.

As the shipping industry considers alternatives to HFO, part of the market will shift towards marine gas oil (MGO) and part towards alternative fuels.

- ▶ Severe PM pollution is clear on emission maps of global shipping routes.

- ▶ IMO implemented a global cap on Sulphur in HFO of 0.5% from January 2020.
- ▶ Changes in IMO and EU maritime regulations on fuel quality and emissions is the driver for cleaner fuels. We see a growing focus on CO₂, methane slip and VOC:
 - ▶ 40% reduction of carbon intensity per transport work by 2030 and 70% by 2050 compared with 2008
 - ▶ 50% reduction of greenhouse gas emissions from ocean shipping by 2050 compared with 2008 SECAs, limiting sulphur content of maritime fuels to 0.1%, are in place in North-America (USA and Canada) and Northern Europe (Baltic Sea, North Sea and English Channel).
 - ▶ Baltic Sea area: only for SOx.
 - ▶ North Sea area: only for SOx.
 - ▶ North American area: for SOx, NOx and PM.
 - ▶ United States Caribbean Sea area: for SOx, NOx and PM (in effect from January 2014).
- ▶ Three local sulphur control areas have been defined in China (Pearl River Delta, Yangtze River Delta and Bohai Bay)
- ▶ Marine vessels equipped with scrubbers will retain the advantage of using lower-priced HFO.
- ▶ Shipping that takes place **outside ECA** areas might choose HFO or low-sulphur fuel oil (LSFO) depending on future global regulations.
- ▶ Ships operating **partly in ECA** areas will probably choose MGO as a compliance fuel.
- ▶ Heavy shipping **within ECA** areas, however, might be incentive enough for a complete shift to **clean fuels**.

Leading marine propulsion engines manufacturers such as **MAN, Wärtsilä, Rolls-Royce, Caterpillar, Cummins** and **GE** have dedicated professional staff with expertise in their company's entire product lines for identifying specific and tailored solutions. The marine propulsion engines market is characterised by frequent mergers and acquisitions in a bid to achieve competitive advantage and extensive R&D.

There are currently three main engines families in the market that can be used to run on LPG as a fuel:

- ▶ In a diesel cycle two-stroke engine, the MAN ME-LGIP series 14,15 as offered by MAN
- ▶ In an Otto cycle, lean-burn, four-stroke engine, the Wärtsilä 34SG series, currently only for stationary power plants.
- ▶ In a gas turbine the LM2500 series, as offered by GE, possibly in combination with a steam turbine or CO₂ turbine.

MAN Energy Solutions has received 79 engines orders for its new MAN B&W ME-LGIP engine.

The market of smaller commercial and recreational vessels with inboard and outboard engines is governed by different criteria, environmental concerns, particularly in protected lake, river and sea areas, together with economic benefits are also drivers to shape the market in the years to come.

- ▶ This market is new and largely based on retrofits and conversions (and some new OEM engine developments), particular attention needs to be played to the “marinisation” of the engines, fuel systems and related equipment, to ensure good protection against corrosion from the sea water.
- ▶ There will also be a strong need for effective training of personnel at all levels in the distribution chain including the users, the introduction of proper procedures and the correct selection of equipment, to transfer and store the product as well as use it as a combustible fuel aboard the vessel.

The role of the various stakeholders is instrumental in driving growth of LPG in the marine sector as an engine fuel.

All principal stakeholders from design offices, marine engine manufacturers, shipyards, classification societies, ship owners, cargo owners, ship operators, policy makers, regulators, governments, LPG industry distributors, associations, need to be addressed with coordinated actions.

The next few years are bound to change the operations of the shipping industry, as there will be a tectonic shift in fuels used and as such, major conversion and retrofit projects on existing vessels. Ship owners will need to begin planning for future-proofing current new buildings.

- ▶ Currently **LPG recreational boats and fishing boats** exist mainly in USA, Chile, Germany, Italy, Spain, UK, Turkey, the Nordic countries and also in the east, such as Indonesia.

VLGCs is an obvious target with significant additional benefits, the Exmar order of two new build VLGC capable of running on LPG, and BW LPG to retrofit fifteen ships to LPG propelled dual fuel, are the first examples leading the way.

- ▶ Other shipping segments of large vessels that have already started using natural gas (mainly LNG) as a fuel can also be a target for LPG, the approaching IMO regulations being a driver.
- ▶ All types and sizes of boats operating in protected areas and emission restriction areas, coastal passenger routes, coastal ferries, fishing fleets are also priority target as marine applications.
- ▶ The COGES concept of GE and associated consortium in South Korea is another example that shows the direction that the industry wishes to take.

Using LPG as fuel can also be a good first step towards use of ammonia when this technology becomes available, due to the compatibility of materials and expected similarities in engine design.

2.2. Key Messages – Roadmap

Whether new builds or retrofitted, LPG fuelled vessels are clearly to play a role in the future. More and more new-builds have been made LNG-ready, making it relatively easy to retrofit to LPG fuelling at a later point.

Short-sea routers, as well as ferries constantly operating between defined ports, are the main target sectors where LPG may offer the biggest advantages. This consideration becomes even stronger when the operation is influenced by sailing periods in Emission Control Areas (ECAs).

LPG carriers, containerships, tankers, cruise vessels, offshore vessels, roll-on roll-off (RoRo), and passenger ferries represent typical vessel fleets that could be converted to LPG operation.

Taking all this into consideration it can be predicted that during the next ten years, LPG will find its way to new ship-builds. Utilising the existing network and infrastructures in order to supply LPG at the necessity points in the world, LPG could potentially be the best solution for the new fuel regulation.

There is growing evidence to suggest that LPG will have a major opportunity to displace traditional marine fuels and to play in the marine market as:

- ▶ Emissions regulations today dictate the use of low sulphur fuels.
- ▶ Alternative fuels like LPG/propane are a viable choice – as they are almost all sulphur free.
- ▶ The higher costs of low sulphur diesel could make the use of alternatives a reality much sooner.

There are several inherent characteristics which support the LPG marine fuel.

- ▶ The increase in global production mainly in Asia and North America creates market opportunities as a big number of “clean” ships will be required to be constructed and operated in that areas.
- ▶ The regulatory drive towards CO₂ abatement initiatives in the light of 2030 regulations.
- ▶ Competitive LPG price.
- ▶ Global trade and industrial market growth.
- ▶ Adequate availability of bunkering infrastructure.
- ▶ Adequate supply of LPG product.
- ▶ Increasing awareness of the advantages of new technologies.
- ▶ Increasing number of new ship orders complying with regulatory developments for marine emissions.

LPG is at least as attractive as LNG with shorter payback periods, lower investment costs and less sensitivity to fuel price scenarios.

LPG as marine fuel faces several strong barriers which need to be overcome:

- ▶ Customer economics: Investment for ship owners and economics for fleet operators.
- ▶ Positioning LPG to policymakers and decision makers: Need to be on a level playing field with other alternative fuels.
- ▶ Technology development of new engines: In recreational sector, there is a slow rate with limited growth. In big vessels, there are few early development projects under development.
- ▶ Commercialisation of the new engines: Sales, servicing and maintenance networks are required.
- ▶ LPG awareness for decision makers: Shared vision with marine engine manufacturers, naval architects and designers, ship owners and ship operators need to be considered.

-
- ▶ Bunkering infrastructure: Development of bunkering infrastructure, uncertainty of LPG supply and bunker price are issues of concern for a ship owner to invest in LPG-fuelled ship.

2.3. Key Messages – Recommendations

LPG industry stakeholders need to work together in a coordinated way in order to overcome the barriers and create opportunities for market entry in the shipping sector. Recommendations to engage stakeholders are briefly mentioned below.

- ▶ Governmental incentives, financial support and technology development in order to overcome the economic challenge of new investments.
- ▶ R&D investment is absolutely key so as to accelerate technology development of new engines.
- ▶ Develop training support and distribution partnerships in new regions for facilitating commercialization and get engines to market.
- ▶ Position LPG to policymakers and decision makers. Lobbying is one of the most important activities to ensure this. Regulations and standards need to be issued wherever not available or not adequate.
- ▶ Participation in market specific conferences or new project developments for different types of vessels to raise awareness of LPG.
- ▶ Establishment of global network of LPG bunkering terminals. The situation is sometimes described as a “chicken-and-egg” dilemma. Until the bunkering infrastructure is in place, ship owners may not commit to LPG fuelled ships and visa-versa.

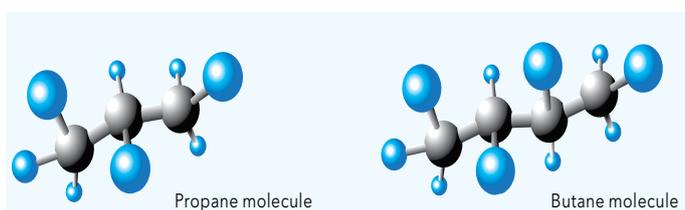
Chapter Three

Fact Sheet

This Fact Sheet provides an overview of the product, the major LPG engine technologies and their major applications in market segments. It provides a snapshot of the main stakeholders on the global market and addresses issues related to safety, quality and market status.

3.1. The Product – LPG as Marine Engine Fuel

The term “LPG”, liquefied petroleum gas, is applied to mixtures of light hydrocarbons which can be liquefied under moderate pressure at normal temperature but are gaseous under normal atmospheric conditions.



It consists predominantly of propane and butane (normal butane and iso-butane), propylene and other light hydrocarbons and its chemical composition can vary. In some countries, the mix varies also according to the season. Since LPG can be liquefied at low

pressures at atmospheric temperature, its storage and transportation is easier than of other gaseous fuels. It is stored under pressure in tanks or cylinders.

3.1.1. Production

LPG is produced either from natural gas processing – mainly – or from oil refining. LPG is a by-product of both these processes. At present, more than 60% of global LPG supply comes from natural gas processing plants, but the share varies markedly among regions and countries.

Natural gas processing

When gas is drawn from the earth, it is a mixture of several gases and liquids. Commercial natural gas is mainly composed of methane. However, it also contains ethane, propane and butane in accordance with the specifications for natural gas in each country in which it is distributed. Therefore, before natural gas is marketed, some NGLs, including LPG (propane & butane) are separated out, depending on the “wetness” of the gas produced: NGLs represent 1 to 10% of the unprocessed gas stream. Worldwide, gas processing is the source of approximately 60% of LPG produced.

Crude oil refining

In an oil refinery, LPGs are produced at various stages: atmospheric distillation, reforming, cracking and others. The LPG produced will be between 1 and 4% of crude oil processed. This yield will depend on the type of crude oil, the degree of sophistication of the oil refinery and the market values of propane and butane compared to other oils products. Worldwide, refining is the source of approximately 40% of LPG produced.

BioLPG/Renewable LPG

BioLPG/Renewable LPG is created from renewable and waste materials. The feedstocks undergo a series of sophisticated treatments to purify their energy content. Just like LPG, BioLPG/Renewable LPG can be used in many different sectors, wherever heat, light or power are required. BioLPG/Renewable LPG is chemically identical to conventional LPG. It can replace conventional LPG but the two can also be blended and used by existing appliances. The mission behind the development of BioLPG is to further reduce carbon emissions. BioLPG/Renewable LPG is not an

innovation for the future, it is already available on the European market in quantities that can service the energy needs of thousands of families and businesses.

Although tied to the production of natural gas and crude oil, LPG has its own distinct advantages and can perform nearly every fuel function of the primary fuels from which it is derived. The fact that it can be easily liquefied makes LPG a highly versatile energy alternative and thanks to a wide variety of packaging and storage options, LPG has numerous fuelling applications.

LPG is a viable alternative gaseous fuel.

It has high energy density compared with most other oil products and other alternative fuels and burns cleaner in the

presence of air. It has high calorific value compared to other gaseous fuels and also high-octane number (but a low cetane number). Its high-octane number makes it suitable for spark ignition engines (SI), while its low cetane number makes it less favourable for use in large proportions in compression ignition engines (CI) – diesel engines.

Clean

- Gas is nature's cleanest fossil fuel
- Gas generates the lowest CO2 emissions per unit of energy

Efficient

- Gas produces more energy per unit than any of the fossil fuels
- LPG is economical. It contains higher calorie value per unit than other commonly used fuels

Widely available

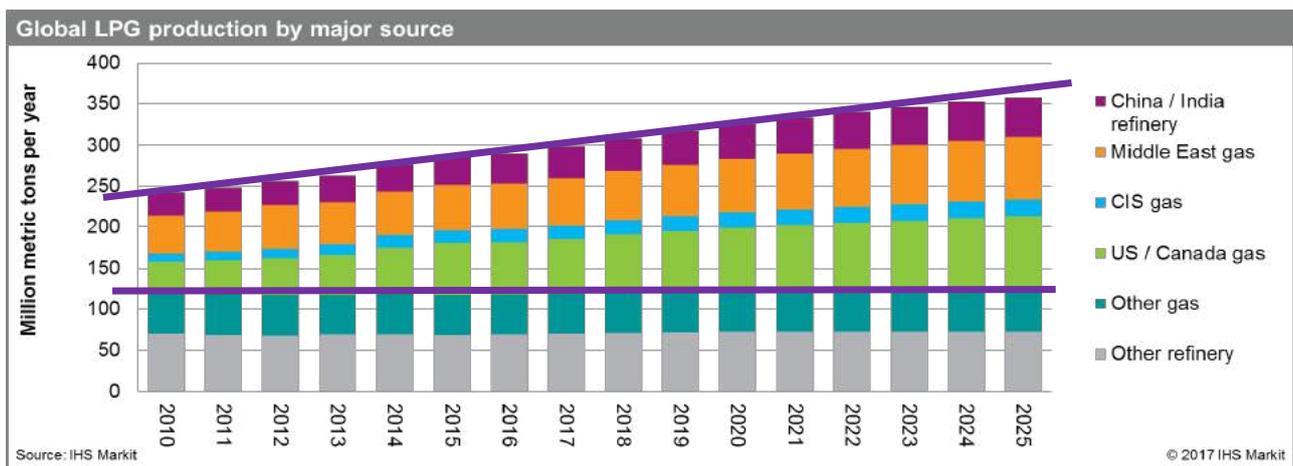
- LPG is portable, can be stored and transported easily
- Size and type of LPG containers can be adapted to local market

CO2 comparison: Gas (+38% CO2 emission), Oil (+95% CO2 emission), Coal (+95% CO2 emission)

LPG is leading the energy transition

3.1.2. Worldwide Production

The global LPG production in 2015, was 284 million tonnes, equivalent to about 310 million tonnes of oil by energy



content, and is increasing by about 2% per year. In comparison, the fuel consumption in the maritime sector was estimated by IMO to be 307 million tonnes on average in the period from 2010-2012. The production increase has been most profound in North America and the Middle East. The production increase in North America in the last few years can be attributed to the substantial increase in shale gas production, which has turned the USA into a net exporter of LPG since 2012.

World LPG Production Facts⁵

There are new fields, pipelines, fractionators, export upgrades and even new terminals which are going to add more LPG product to the international stage by 2025.

Worldwide LPG Projects

- ▶ Inpex, Japan's largest oil & gas exploration and production company, brought the \$40 billion Ichthys project in western Australia into operation late 2018. Production so far has been extremely strong and it is expected to produce 8.9 million Mt/y of LNG and 1.7 million Mt/y of LPG.
- ▶ Shell's Prelude FLNG facility, 475 kilometres north of Broome in western Australia, also started operation at the end of 2018 and the first condensate shipment took place in 2019. Here LNG production is forecast to be 3.6 million Mt/y and LPG at 0.4 million Mt/y, as the field is more condensate rich.
- ▶ Various expansions on stream were added to the South Pars field in Iran in March 2019.
- ▶ Japanese EPC contractors JGC announced that the \$350 million Central Gas Plant Three (CGP-III) project in Bahrain was due to start commercial operations following the completion of commissioning work. This will recover about 0.2 million Mt/y of LPG. A new 30,000 Mt refrigerated storage will be built.
- ▶ There are projects in Saudi Arabia, and the Jazan Refinery Project in the south west of the country is the first to come on stream. It is a \$9 billion project in two phases, a simple hydro skimming refinery to start off, running 400,000 barrels a day, and producing 0.6 million Mt of LPG at full capacity. It is slated for export and there is a major marine terminal associated with it.
- ▶ The Kuwait National Petroleum Company (KNPC) have their Gas Train-5 project due for commissioning by early 2020. This will increase LPG production in Kuwait by up to 1.8 million Mt/y at full capacity.
- ▶ Equinor are developing the giant John Sverdrup field in the Norwegian sector. At peak production, it will account for a quarter of Norwegian oil output. Oil will be processed in Mongstad and gas via Statpipe to Karsto. LPG production from John Svedrup is likely to reach 0.4 million Mt/y.

There is significantly more non - USA production growth potential already identified, and yet there is still more to come beyond 2020. The USA will certainly be the primary source of production growth over the next four to five years, but we should not dismiss the importance of other regional projects and their impact on the overall seaborne trade.

3.1.3. Transportation

The global LPG trade was approximately 95 million tonnes in 2018 and hence about one third of the LPG is exported⁶. LPG can be transported by three different ship types, depending on how the cargo is stored:

- ▶ refrigerated, typically at -50°C at close to ambient pressure.
- ▶ semi-refrigerated, typically at -10°C and 4-8 bar pressure.
- ▶ under pressure, typically at 17 bars, corresponding to the vapour pressure of propane at about 45°C.

There are currently about 300 very VLGCs.

⁵ ETAI (2019)

⁶ IHS Waterborne, NGL Strategy, Kpler, BW LPG Analysis

Global LPG imports by VLGC are expected to increase ⁷

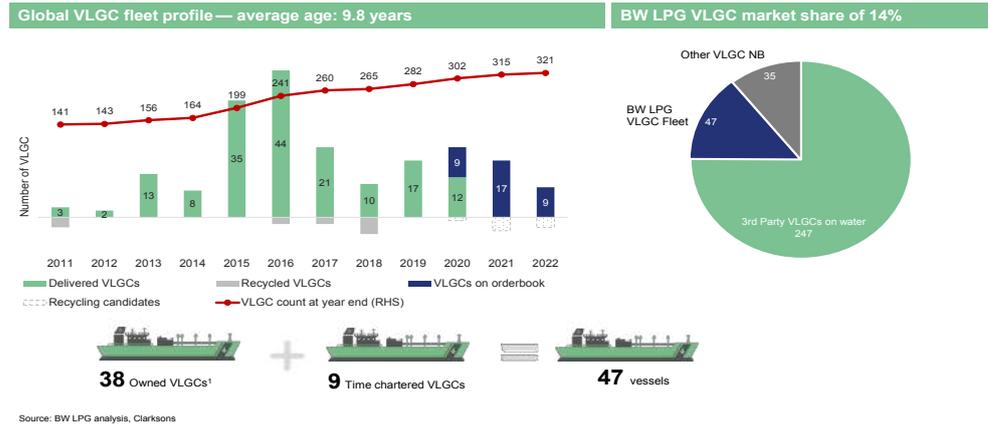
Global total imports by VLGC will reach 98.5mt in 2025 from 69.1mt in 2018. Far East will absorb 50% of the increase, followed by Indian Ocean and Southeast Asia.

Semi-refrigerated ships typically have a capacity of 6,000 to 12,000 m3, whereas compressed LPG ships typically take 1,000 to 3,000 m3.

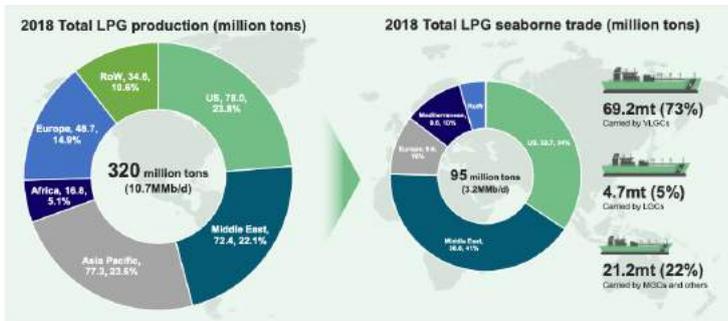
The transportation of LPG is covered by the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), which is aimed at the safe carriage of liquids with a vapour pressure above 2.8 bar at 37.8°C, and applies to all ship sizes. If an LPG carrier was to be

VLGC Fleet Profile

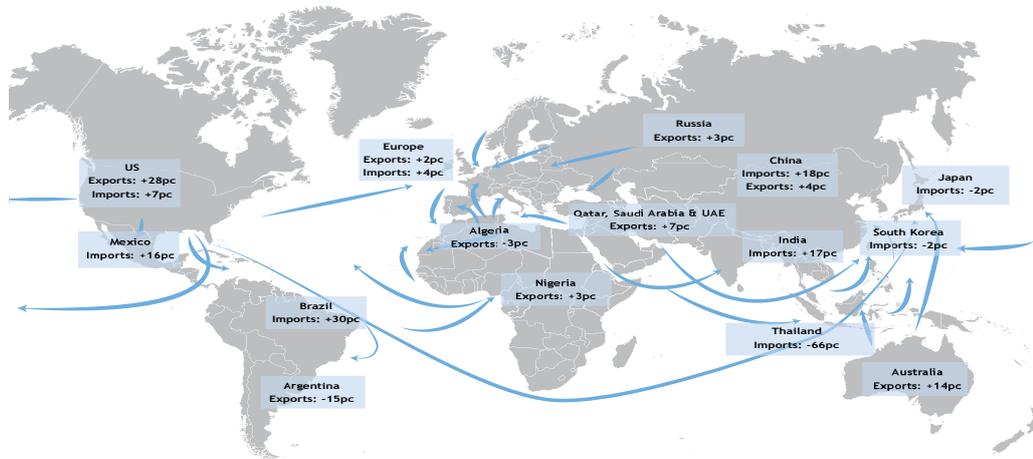
294 ships on water with 12 ships delivered within Q1 2020. Orderbook at 35 ships or 12%



powered by LPG, this is in principle for this particular ship type covered by the IGC Code without having to comply with the IGF Code (International Code of Safety for Ship using Gases or Other Low-flashpoint Fuels). However, the IGF Code



can be used for further clarification. For other ships, the use of LPG as fuel has to be covered through alternative compliance with the IGF Code.



⁷ BW LPG

3.1.4. Bunkering

A large network of LPG import and export terminals is available around the world to address trade needs. Recently more



LPG export terminals have been developed in the USA to cover the increased demand for competitively priced LPG products. In figure below, **import and export terminals of various sizes in Europe are shown** to illustrate this point, while many other storage facilities can be found in several additional locations. In these locations, it is possible to develop bunkering infrastructure by creating distribution systems in addition to the existing storage facilities.

LPG can effectively be supplied as a bunker fuel to vessels using existing facilities such as terminals and refineries, saving on initial costs to develop infrastructure. There are likely to be more than

1,000 such facilities that have pressurised LPG storage tanks around the world. It is typically easier to liquefy LPG than LNG, making it more economical and easier to handle as a bunker fuel.



Main Bunkering Hubs

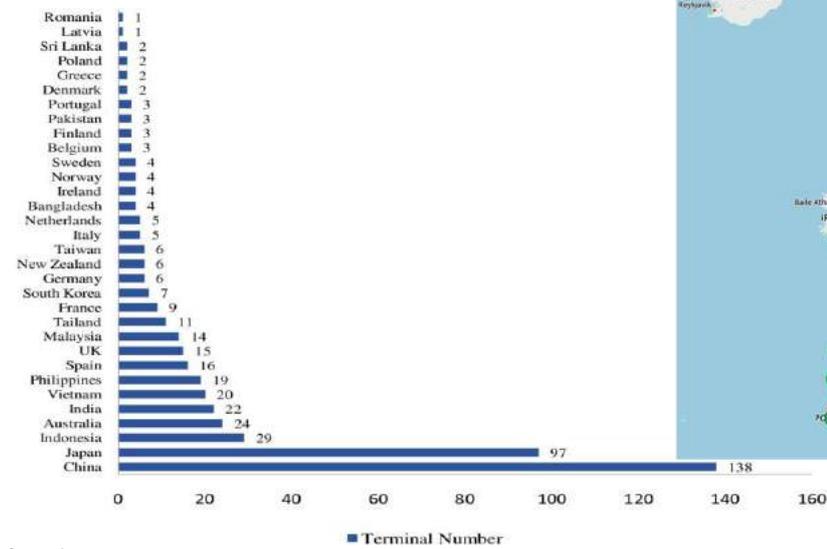
Singapore, Rotterdam, Fujairah and Houston are the world's top four major bunkering hubs. Other key global bunkering ports include Antwerp, Hong Kong, Gibraltar, Panama and Los Angeles/Long Beach.

Just six countries are responsible for almost 60% of global bunker sales⁸. Even though there are approximately 400

⁸ World Oil Outlook

major bunkering ports in the world, most of the demand is concentrated in a few strategic ports.

Number of LPG terminals



Source: Argus

Rotterdam, the biggest port in Europe, is the third largest bunkering port with annual sales of around 10.5 million MT. Hong Kong and Antwerp complete the world's top five bunkering ports by volume, with annual sales of 7.4 million MT and 6.5 million MT respectively.

Other important ports include **Busan (South Korea), Gibraltar, Panama, Algeiras (Spain), Los Angeles/Long Beach (US) and Shanghai (China)**

In all the above hubs, it is possible LPG to be provided as bunker fuel.

Example 1:

STS LPG bunkering can now take place at Portland Port

LPG ship to ship (STS) bunkering has been authorised at a UK port to help it support sustainable fuel usage in commercial shipping. STS transfers of LPG product can now take place in the inner or outer harbour and alongside at Portland Port

in Dorset. STS Marine Solutions has been working with Portland Port to finalise the project and is the first company that has been issued with a certificate by Portland Harbour Authority to manage LPG STS operations within harbour waters. It has deep water with sheltered anchorages and berths, all of which is in close proximity to the main English Channel shipping lanes.



Portland Port

LPG operations management

STS Marine Solutions will screen the vessels that are going to be involved in LPG bunkering for suitability and compatibility based on location, equipment available and weather conditions.

Example 2:

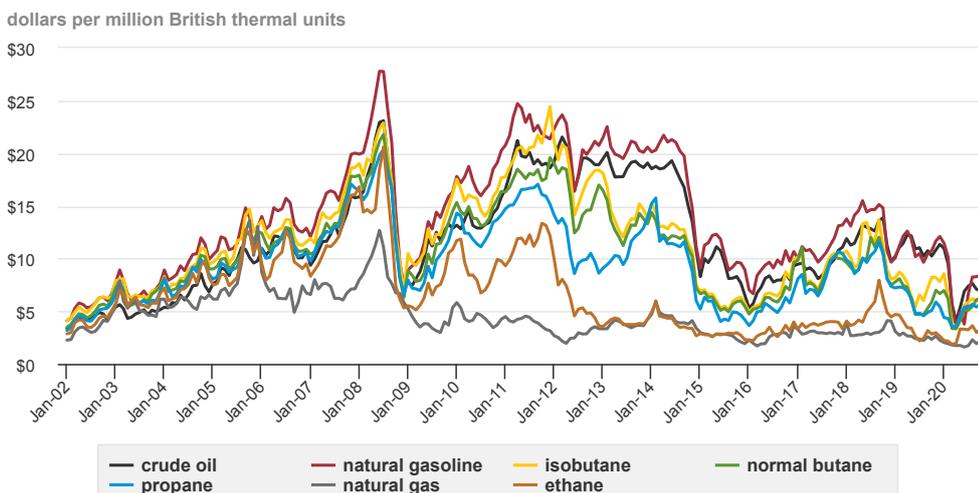
Port of Fujairah in United Arab Emirates

In preparation of the IMO 2020 transition, the Port of Fujairah, which is among the three biggest bunker markets in the world, implemented several strategies in terms of infrastructure which provided a soft landing during the COVID-19 lockdowns last year. While it is working on developing LNG bunkering infrastructure, the port is also considering establishing LPG loading arms to its facility as it receives increasing inquiries for the sector.

3.1.5. Pricing

LPG is traditionally a cheaper fuel than marine gas oil (MGO). Using our dual-fuel engine technology, it is possible to take advantage of fluctuating fuel prices in the future. Importantly, the ability to use LPG cargo as a supplement fuel source provides significant cost savings for VLGC owners or charterers, including reduced time and fees for fuel bunkering.

Spot prices for hydrocarbon gas liquids, natural gas, and crude oil, January 2002-October 2020



Note: Prices are monthly average of close-of-day spot prices; crude oil is Brent; natural gas is Henry Hub; HGL products are at Mt. Belvieu non-LST (Lone Star Terminal).

Source: U.S. Energy Information Administration from Bloomberg

Since 2011, LPG has been sold in the USA, on an energy basis, at a discount to crude oil, but significantly higher than that of natural gas as shown on the Figure on the left. A decoupling of LPG and oil prices, and the reduction in the price of LPG may be attributed to the increased yield of propane from shale gas production. This development also resulted in the US turning from a net

importer into a net exporter of LPG after 2011.

Normal butane has about 10% higher volumetric energy density than propane, but is typically more expensive. Furthermore, in outboards engines the high boiling point of normal butane prevents the use of pure butane in colder climates. **Therefore, the use of propane or propane-rich mixture of LPG is expected for small boats, and butane when LPG is used as fuel for ships.**

Natural gas liquids spot prices



Sources: NGL spot prices from Bloomberg, L.P., and weights for NGPL composite price from EIA-816, Monthly Natural Gas Liquids Report.

Notes: NGL spot prices at Mont Belvieu, Texas. Monthly volumes from EIA-816 used to calculate weights for the NGPL composite price. EIA-816 volume weights are constant throughout a given month, and the latest available weights are applied to the three most recent months. Natural gasoline is the term used in the spot and futures markets to describe pentanes and hexanes, the primary components of pentanes plus.

3.1.6. LPG propulsion – Fuel Cost Benefits

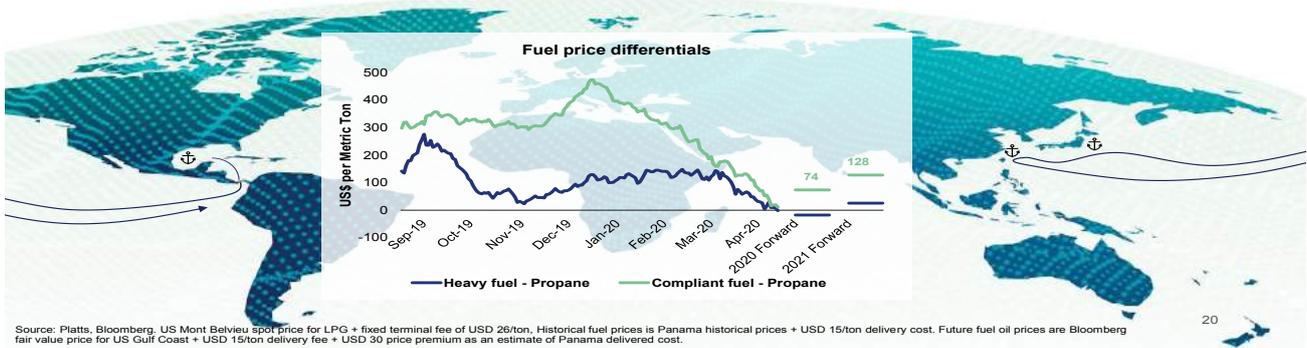
With retrofitted dual fuel engines, there is the option to run on LPG when it is more attractively priced, reducing the overall fuel price risk, though conversion is slightly more expensive than scrubber retrofitting.

- ▶ Economic efficiencies
- ▶ Savings from reduced fuel consumption
- ▶ Buffered from fuel price sensitivity with full dual-fuel flexibility
- ▶ Seamlessly switch between LPG and compliant fuels
- ▶ More efficient engines are cheaper to maintain

Estimated fuel consumption

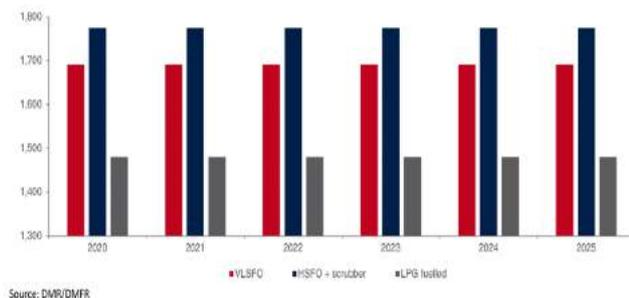
- 10% and 15% lower consumption vs compliant fuel and scrubbers
- USD 20/ton fuel cost savings from replacing fuel oil barge with loading LPG at the terminal
- Lower price of LPG compared to compliant fuel for both 2020 and 2021
- Price differentials have decreased following the recent collapse of oil prices. However, we expect the price differentials to widen again when oil market recovers

Price differentials between Compliant fuel and Propane (US\$/ton)	US\$ per day savings	US\$ per year savings	Payback time (years)	IRR
0	\$2,000	\$540,000	18.5	1%
\$100	\$5,000	\$1,350,000	7.4	12%
\$128	\$6,000	\$1,620,000	6.2	15%
\$150	\$7,000	\$1,890,000	5.3	18%
\$250	\$10,000	\$2,700,000	3.7	26%

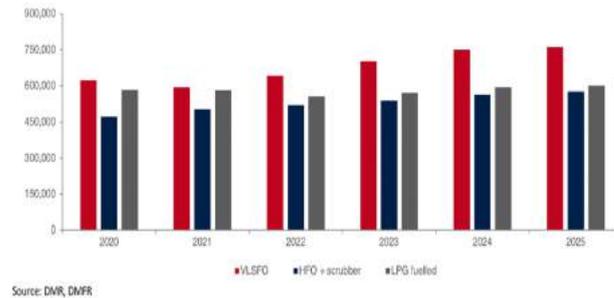


The upfront cost of LPG propulsion retrofitting is significantly higher than that of scrubber retrofits with scrubbers costing anywhere between US\$2M and US\$3M per vessel. However, the direct impact can be seen in fuel consumption. Based on calculations by Drewry, there should be at least a 15% reduction in fuel consumption as compared with high-sulphur fuel oil and 12% reduction in fuel consumption as compared to low-sulphur fuel oil over the next five years. While LPG is perhaps the best bet in terms of fuel consumption, it loses out on fuel costs. HSFO leads the tally by only 4% as compared with LPG and a whopping 32% when compared with compliant low-sulphur fuel. This makes LPG an ideal candidate among the three options, which is further affirmed by the earnings per day commanded by each vessel type. Based on their estimations and calculations, an LPG-fuelled vessel should overtake an HSFO-fuelled vessel by 2023. According to Drewry's assumptions of earnings and fuel consumption, when taking into account the US\$9M upfront capital expenditure, the payback period for a new build vessel costing close to US\$80M increases by about eight months.

Estimated fuel consumption (tonne) per voyage for a VLGC on AG-Japan

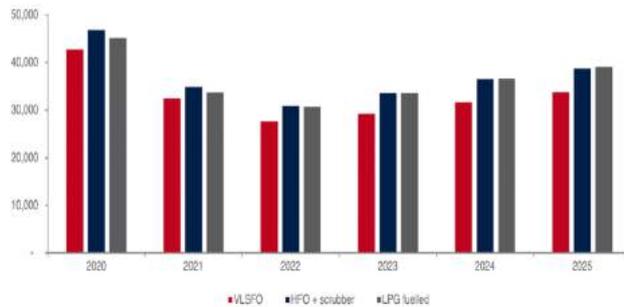


Estimated cost (\$) of fuel per voyage for a VLGC on AG-Japan route



This presents a lucrative opportunity, as any earnings beyond that period would enhance the cash flows. It makes both economic and environmental sense to switch to dual-fuel LPG engines, mainly for young or new mid- to large-sized vessels.

Estimated daily TCE (\$/day) for different fuel types



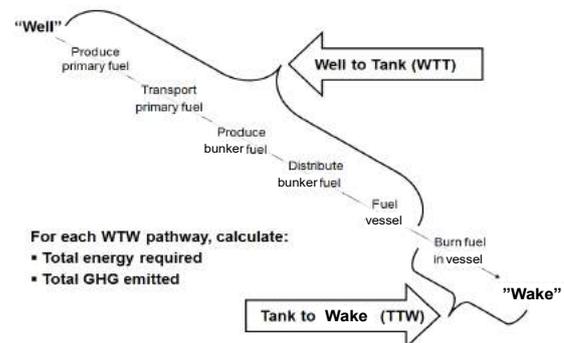
Source: DMR, DMFR

3.1.7. Environmental, emissions to air and water

LPG combustion results in lower CO₂ emissions compared to oil-based fuels due to its lower carbon to hydrogen ratio. Compared to natural gas CO₂ emissions are a bit higher, but some gas engines can suffer from methane slip, which increases their overall greenhouse gas emissions. Considered in a lifecycle perspective, LPG production is associated with lower emissions than oil-based fuels or natural gas. The combination of low production and combustion emissions yields an overall greenhouse gas emissions reduction of 17% compared to HFO or MGO. This is comparable with the greenhouse gas emissions from LNG, which strongly depend on the amount of methane leak and could be slightly lower or higher depending on the production and combustion technology.

Alternative fuels

Basis for CO₂ calculation



MAN Energy Solutions

Public

Prospects for energy and maritime transport in the Nordic region

Greenhouse gas emissions in kg CO₂eq/GJ for oil-based fuels, LPG and LNG are given in the table below. A methane slip of 1% and an energy consumption for liquefaction of 7% are assumed for LNG. Because the global warming potential for LPG and n-butane are three, and for isobutane four times the global warming potential of CO₂, compared to 25 for methane, any slip of un-combusted fuel through the engine would result in less greenhouse gas emissions for LPG than for LNG.

The use of LPG also has benefits related to pollutant emissions. It virtually eliminates sulphur emissions, and can be used as a means of compliance with low sulphur local and global regulations. The reduction of NO_x emissions depends on the engine technology used.

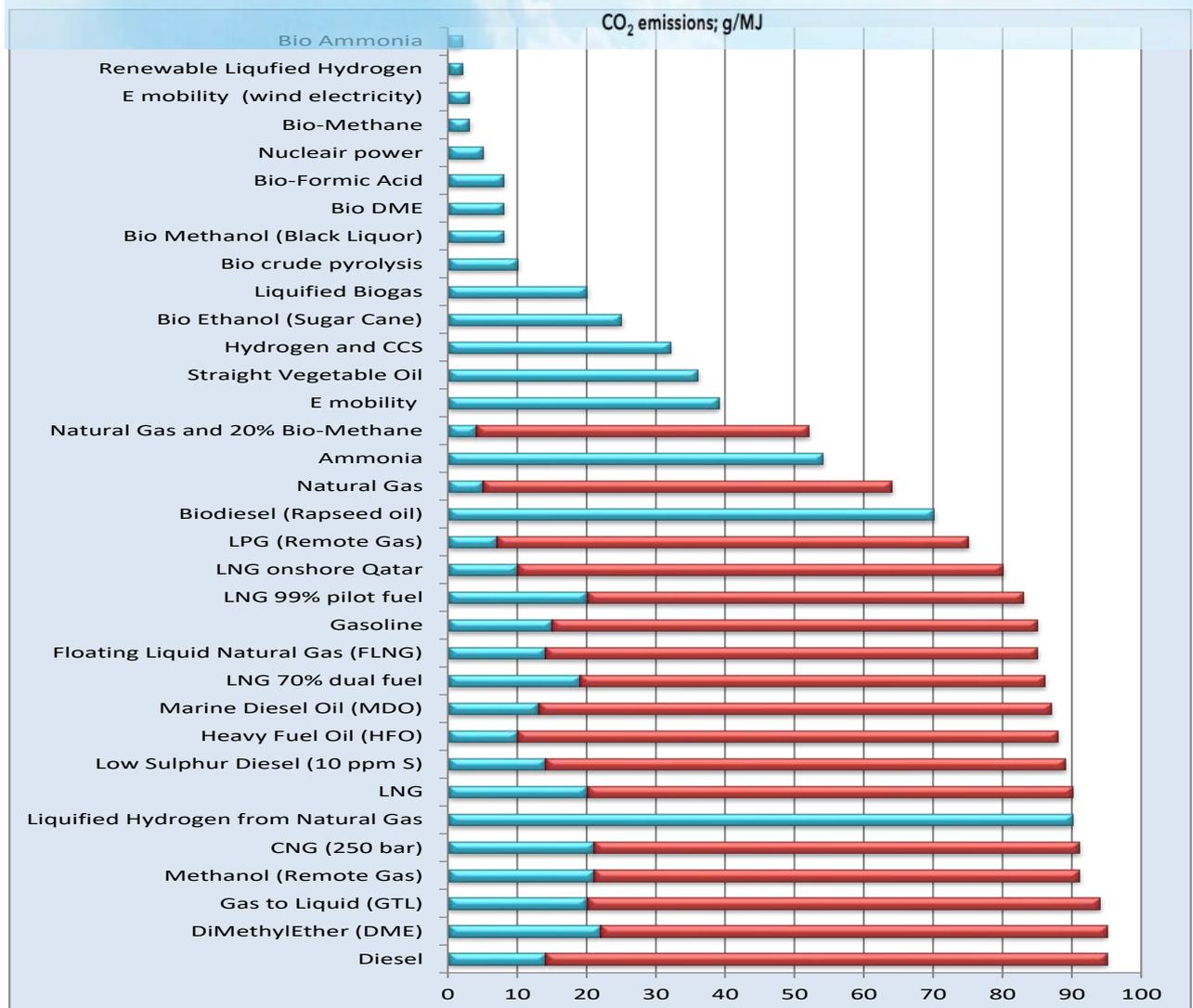
For a two-stroke diesel engine, the NO_x emissions can be expected to be reduced by 10–20% compared to the use of HFO, whereas for a four-stroke Otto cycle engine, the expected reduction is larger and may be below Tier III NO_x standards. In order to comply with these standards, a two-stroke LPG engine should be equipped with Exhaust Gas

Recirculation (EGR) or Selective Catalytic Reactors (SCR) systems. Both solutions are commercially available. The use of LPG as a fuel will, like LNG, to a large degree avoid particulate matter and black carbon emissions.

CO₂ Emissions of Fuel Alternatives in Shipping



4.2 WTP CO₂ performance of potential marine fuels



3.1.8. Order book

LPG marine fuel is available now, diesel engines can be also retrofitted to burn it.

SHIPPING COMPANY/OWNER	SHIP TYPE/SIZE (M3)	ENGINES ON ORDER	OPTIONAL ENGINE ORDERS	ENGINE TYPE	SHIPYARD	ESTIMATED TIME OF DELIVERY	CLASS
NEW BUILDS							
Exmar	LPG VLGC 86,000 cbm	2	8	6G60ME-C9.5-LGIP	Jiangnan Shipyard Group	2Q/4Q 2021	Lloyds Register
East Pacific Shipping with Equinor Gas	Medium size LPG carriers 38,553-m3	3		MAN 2 stroke	Hyundai Mipo Dockyard	2022	
Tinjin S.W.Southwest Maritime (TSM)	LPG VLGC 86,000 cbm	1	1	6G60ME-C9.5-LGIP	Jiangnan Shipyard, owned by China State Shipbuilding Corp (CSSC)	The first 2H 2021	
Kumiai Navigation	LPG VLGC 84,000 cbm	3		7G60ME-C10.5-LGIP	KHI	2H 2021 / 1Q 2022	
Kumiai Navigation	LPG VLGC 40,000 cbm		1		KHI		
Avance Gas Holding (AGAS)	LPG VLGC 91,000 cbm	2	2	7G60ME-C10.5-LGIP	South Korea's Daewoo Shipbuilding and Marine Engineering (DSME).	4Q 22/1Q 23	Lloyds Register
Geogas	LPG VLGC 91,000 cbm	2		7G60ME-C10.5-LGIP	Hyundai Samho Heavy Industries (HSHI)		
NIETO	LPG LGC 38,000 cbm	1		7G50ME-C9.6-LGIP	HMD	2020	Lloyds Register
Byzantine Maritime	LPG LGC 38,000 cbm	2	2	7G50ME-C9.6-LGIP			Lloyds Register
Hartmann	LPG Tanker 5,000 cbm	3	2	5S35ME-9.7-LGIP	CIMC-SOE	2H 2021	
Trafigura (Trading company)	LPG VLGC 84,000 cbm	2	4	6G60ME-C9.5-LGIP	HSHI	2023	
IINO Kaiun Kaisha	LPG VLGC 91,000 cbm	2	3		(DSME).	1Q 2023	
Union Maritime	LPG VLGC 84,000 cbm	1	1		Hyundai Heavy Industries	2022	
NYK Lines (Japan)	LPG VLGC 91,000 cbm	2			KHI	2022	
Petredc Holdings (Eastern) PTE Ltd ("Petredc")	LPG VLGC 93,000 cbm	6			Jiangnan Shipyard (Group) Co. Ltd	January, March and May 2023 and the other vessels within Q2 and Q3 2023	DNV
RETROFITS							
BW LPG	LPG VLGC	15		6G60ME-C9.2-LGIP	China	2H 2020/2021	DNV
TOTAL	71	47	24				



BW LPG: GEMINI 80,000 m3 VLGC the world's first LPG-fuelled vessel on the water.

3.1.9. Main Advantages of LPG as Marine Fuel

- ▶ Available in large quantities everywhere in the world and in production surplus. LPG is soaring in the wake of rising global natural gas production. The US is the main supply of incremental production going forward considering that many of its gas deposits are especially wet which means that they contain a large fraction of gas liquids such as butane and propane. Indeed, for the moment, supply is outstripping demand and this is projected to continue over the medium-term. According to the WLPGA, this surplus could hit 27 million tonnes per year going forward. This overhang represents approximately 12% of global international bunkering demand.
- ▶ Offers the longest running range of any alternative fuel option. Due to a higher-octane rating and efficient combustion, LPG engines can use higher compression ratios resulting in more power and better fuel efficiency.
- ▶ Meets worldwide emissions standards/IMO requirements, therefore a switch to LPG has significant potential in emissions reduction of hydrocarbons, CO, CO₂, also NO_x, GHGs and PM in general.
- ▶ Reduces VOC evaporative emissions/ a new requirement in commercial ports around the world.
- ▶ LPG is nontoxic, hence not harmful to soil or water when spilled or leaked. Gasoline and diesel fuels in the water are harmful to humans and in many cases fatal to aquatic life. Floating fuels and oils are also particularly noxious because they reduce light penetration and the exchange of oxygen at the water's surface.
- ▶ LPG is stored at lower pressures than i.e. CNG making storage tanks lighter and more economical.
- ▶ Cleaner and easier to install, maintain and handle.
- ▶ Harnessing LPG propulsion translates into cleaner, more efficient engines that are cheaper to maintain. In addition, LPG has a range of properties that enables it to be used in hundreds of different applications. I
- ▶ It has lower lifecycle costs - lower cost for ship owner.
- ▶ It saves bunkering time for large LPG tankers that can use the cargo as fuel.
- ▶ It is more economic (LPG prices vs fuel oil prices)
- ▶ It is an increasing availability of LPG network. Small investment is required to setup an LPG bunkering point.

3.1.10. LPG Propulsion Sustainability in Summary⁹

LPG as a marine fuel for VLGCs offers multiple efficiency gains.

Environmental Sustainability

Cleaner fuel-lower emissions

- ▶ Move maritime industry closer to a cleaner future of zero carbon propulsion
- ▶ LPG versus compliant fuel
 - ▶ Consumption down by ~10%
 - ▶ Sulphur oxides down by ~99%
 - ▶ Particulate matter down by ~90%
 - ▶ Greenhouse gases down by ~15%
 - ▶ Nitrogen oxides down by ~10%
- ▶ LPG vs scrubbers
 - ▶ Consumption down by ~15%
 - ▶ Sulphur oxides down by ~99%
 - ▶ Particulate matter down by ~50%
- ▶ Greenhouse gases down by ~20%
- ▶ Nitrogen oxides down by ~10%

Economic Sustainability

- ▶ **Improved Efficiencies**
 - ▶ Full compliance with current and future SOx emission requirements, including ECA and CECA areas
 - ▶ Technology for LPG marine engines is a necessary and complementary step towards zero-carbon propulsion technology
 - ▶ Fuel flexibility of dual-fuel engines ensures optionality and full redundancy for uninterrupted operations
 - ▶ Easier to handle and operate compared to fuel oil or LNG
 - ▶ Elimination of bunker quality issues, spill risks and waiting time
- ▶ **Cost Savings**
 - ▶ Savings from reduced fuel consumption
 - ▶ Buffered from fuel price sensitivity with full dual-fuel flexibility
 - ▶ Seamlessly switch between LPG and compliant fuels
 - ▶ More efficient engines are cheaper to maintain
 - ▶ Lower installation costs and cheaper operating and maintenance requirements than LNG equivalents
 - ▶ Higher energy content, thus lower fuel consumption
 - ▶ Bunkering directly at load terminal saves time for bunkering and costs for bunkering barge
- ▶ **Future Proof**
 - ▶ Full compliance with current and future SOx emission requirements, including ECA and CECA areas

⁹ BWLPG

- ▶ Technology for LPG marine engines is a necessary and complementary step towards zero-carbon propulsion technology
- ▶ Technology is a stepping-stone towards ammonia as a zero-carbon emission fuel cleaner and easier to store and handle environmental benefits similar to LNG, with one major improvement of no methane slip

▶ **Readily Available Supply**

- ▶ Large network of import and export terminals around the world can become LPG bunkering points
- ▶ Ship-to-ship from smaller LPG carriers (~500 vessels in service)

▶ **Operational Efficiencies**

- ▶ Cleaner engines, cheaper maintenance
- ▶ Improve output efficiencies by ~11%
- ▶ Improve total voyage fuel economics
- ▶ Easy storage, faster refuelling
- ▶ Wide availability of bunker ships and facilities

There are advantages especially **for small boat** engines:

- ▶ LPG is more reliable for occasional used equipment as are often the outboard engines.
- ▶ LPG meets local/regional/global emissions standards for inland water ways lakes rivers.
- ▶ An LPG filling station installed on pontoons for marine use, with tank and dispenser unit, costs at about 70,000-80,000 thousand Euro and can be easily and quickly positioned at any place without any environmental and pollution risk.
- ▶ In the UK, many seaports have LPG filling stations, and more are located around Europe e.g. Germany, Venice etc.

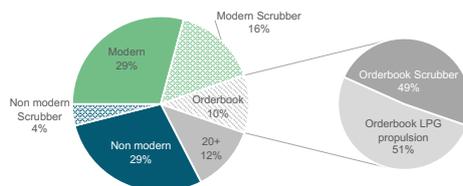
Retrofitting of existing vessels

Compared with a new build, retrofitting an existing ship:

- ▶ Emits 97% less carbon during construction
- ▶ Takes two months, versus two years to complete
- ▶ Does not add unneeded shipping capacity to the market
- ▶ Retrofitting offers significant environmental and economic benefits

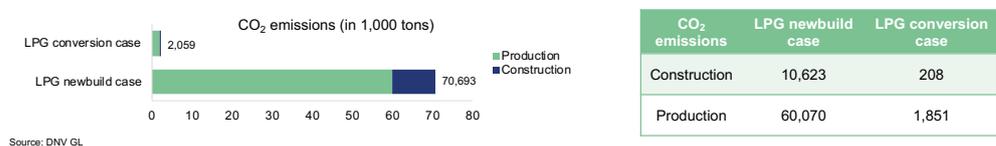


Global VLGC fleet – majority of modern vessels



Source: BW Analysis as of 24th April 2020

Carbon footprint of retrofitting an existing VLGC is substantially lower than building a new VLGC



Source: DNV GL

3.2. Marine Engine Technologies

Clear majority of ships today use diesel engines similar in principle to those in cars, trucks, and locomotives. However, marine fuels differ in many aspects from automotive engine fuels. The viscosity of marine fuels is generally much higher, up to 700 cSt, whereas road diesel fuel rarely exceeds 5 cSt. The quality of marine fuels is generally much lower and the quality band is much wider than are those of land-based fuels. Therefore, marine engines must accept many different fuel grades often with levels of high sulphur content that would seriously harm the function of exhaust gas recirculation (EGR) and catalyst systems on automotive engines. This also means that traditional emissions abatement technologies for road based transport such as diesel particulate filters, exhaust gas recirculation systems, and oxidation catalysts cannot easily be used on ships. The risks of sulphur corrosion and very high soot emissions call for different solutions such as scrubbers or alkaline sorption systems as separate solutions or in combination with technologies known from road-based emissions abatement technologies.

Today diesel engines are the principal means of marine propulsion. These are broadly classified into following categories:

- ▶ **High speed four stroke engines (>1000rpm)**
- ▶ **Medium speed four stroke engines (300-1000rpm) and**
- ▶ **Low speed two stroke engines (<300rpm)**

While some ships, due to their design and operational profile, use either slow or medium speed diesel engines as the principal mode of propulsion, most ships are fitted with additional medium or high-speed diesel engines to drive generator sets for auxiliary power purposes.

Engines of interest mentioned below include those that can be converted to run on LPG. Marine engines can be categorised as below:

- ▶ **Mono fuel engines**

These engines use solely LPG as a fuel. Many of this type need to be converted from diesel (requiring major adjustments, parts of the engine need to be rebuilt). When conversion is made from diesel to LPG, the CO₂ savings are lower than could be expected based on energy content, averaging an emission reduction of about 10-20% CO₂, although the marine diesel engines are about 30% more efficient than Otto engines, due to their higher compression ratio.

- ▶ **Dual fuel engines**

In these engines, LPG and diesel could be combusted simultaneously in a diesel engine. The CO₂ savings are as high as can be expected based on energy content. This technology could involve two fuel systems on the ship. Typically, a small quantity of marine fuel oil is used as pilot fuel, to initiate the ignition process, followed by combustion of the selected alternative fuel. The ship can run on a variable combination of the available fuels. For instance, a variation of 100% diesel up to 97% LPG and 3% diesel is possible, resulting in high CO₂ savings and high variable cost savings.

Marine diesel engines in operation worldwide are slowly changing into dual combustion engines (dual fuel diesel engines (DFDE) that operate on natural gas (potentially on LPG) and marine diesel heavy fuel oil. The dual combustion engines are gaining more importance due to their efficient performance and proven reliability when compared to diesel engines, which are highly prone to pollution.

- ▶ **The Tri Fuel Marine Engine**

The tri-fuel engine technology is already present in the marine market and is mainly used for LNG ships with marine

diesel oil, heavy fuel oil, and LNG used together as marine fuels. This concept was introduced by Wärtsilä and MAN for gas carrier ships and is now going through research and development for using the tri-fuel engine in container ships. The first implementation of such engine is under process on a 7300 TEU container ship undertaken by Wärtsilä. New gas ignition auxiliary engines will be installed in this ship which will run on tri-fuel technology.

3.2.1. High-speed engines (>1000rpm)

The role of high-speed diesels engines in the marine world is expanding. Such engines offer **increased efficiency and reduced cost**. The quest for obtaining more and more power out of smaller engines demands greater efficiency and that in turn can lead to reduced emissions. Most high-speed diesels on the market today can, or will be able to, meet the tier II emission requirements by selective tuning and internal changes to the engine. When it comes to tier III levels of emission control then it does seem that in most cases external features will have to be added to the exhaust system, such as filters and catalytic converters. There is a great deal of research going on to see what will be required to meet these low emission levels and it seems likely that the need for external requirements will be considerably less than at first thought.



Ship builders are developing innovative propulsion solutions where the high-speed diesel forms part of a fully integrated propulsion system. Part of this move towards using high speed engines comes from ECA and local port requirements in many parts of the world, under which low sulphur fuels must be used.

High speed diesels cover a wide range of power outputs from the smallest engines of perhaps 10bhp, up to the mighty top-range V20 8000 MTU diesels that can produce over 12,000bhp. It could be easy to lump all these together as high-speed diesels but there are significant differences between the large and small engines in the high-speed ranges. Above this size, and up to perhaps 2,500bhp to 3,000bhp, the engines used in the marine sector are largely based on engines used for mining, military and rail use.

LPG is considered to be a commercially viable alternative on the high-speed engine market however no engine manufacturer has yet offered a commercially available concept in that field.

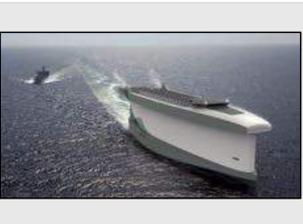
Recent developments

Rolls-Royce's high-speed engine unit MTU have developed and put on the market the first high-speed "multipoint-sequential gas feed marine engine" to operate on pure gas.

Dutch shipping company Doeksen officially commissioned the Willem Barentz, the first of its two new 70-m ferries, on 1st July 2020 in Harlingen. The occasion also marked the premiere of the twin 16-cylinder MTU gas engines from Rolls-Royce aboard the ferry which together deliver some 3,000 kW for its ecologically clean operation on the Wadden Sea, a UNESCO World Heritage site. A pair of 746-kW, 8-cylinder versions of the gas engine were supplied to the city of Constance public utility at the end of 2019 for the new Lake Constance ferry.



Engine portofolio – natural gas

<p>C26:33L (1,4 – 2,4 MW) Bore 260mm Stroke 330mm Speed 900 & 1000rpm Fuel: Natural Gas 6-8-9 cylinders Propulsion and Gen sets</p>			
<p>B35:40L/V (3,3– 9,4 MW) Bore 350mm Stroke 400mm Speed 720 & 750rpm Fuel: Natural Gas 8-9-12-20 cylinders Propulsion and Gen sets</p>			
<p>B36:45 (3,6 – 12 MW) Bore 360mm Stroke 450mm Speed 720 & 750 rpm Fuel: Natural Gas 6-8-9-12-16-20cylinders Propulsion and Gen sets</p>			

3.2.2. Medium-speed engines (300-1000rpm)

Medium-speed diesel engines operate on either diesel fuel or heavy fuel oil by direct injection in the same manner as low-speed engines. Medium-speed engines offer the low ownership costs and high reliability that commercial operators require to carry cargo or people between ports as economically as possible. These propulsion engines are also compatible with a wide range of fuel sources, offering a number of alternatives to more traditional marine diesel and gas oils. Medium-speed marine engines can be configured to run on LNG, CNG or LPG. Engines can be supplied on a single main or multi-engine basis and, all engines are suitable for both diesel-mechanical and diesel-electric drives with ratings from 1,020 kW (1,390 bhp) to 16,000 kW (21,760 bhp).



The six leading manufacturers of medium-speed diesels in terms of ship numbers powered are Caterpillar (including MaK), Wärtsilä, Rolls-Royce, Niigata, Yanmar and MAN Diesel & Turbo.

Wärtsilä 34SG-LPG

The Wärtsilä 34SG is the first medium-speed engine capable of running on LPG. It is also the largest engine running on LPG on the market. The LPG engine is not a new engine type, but the Wärtsilä 34SG is optimised for using propane.

It is a lean-burn Otto gas engine with a spark plug or pilot fuel injection for ignition. This type of engines is characterised by their lean-burn operation, which consists a lean air-gas mixture being introduced into the cylinder, in other words more air than needed for stoichiometric combustion. This strategy results in a lower peak temperature during combustion and, consequently, lower NOX emissions. The accurately control of the exact air-gas ratio, means that the engine can operate without knocking or misfiring while maintaining high thermal efficiency. Ignition of the mixture is initiated using either with a spark plug located in a pre-chamber or pilot fuel injection. The gaseous fuel is introduced into the cylinder through gas admission valves located immediately upstream of the air intake valves. The gas valves are controlled independently of the air intake valves, to feed the correct amount



Medium speed diesel engine Wärtsilä

of gas to each cylinder at the correct timing. The Otto gas engine concept requires a relatively low gas pressure of about 4–5 bar, and thus does not require additional equipment such as pumps and/or compressors to pressurize the gas before it enters the engine.

The Wärtsilä 34SG-LPG is the first **medium-speed engine** capable of running on LPG and the same engine can be used with natural gas and ethane. The fuel switch takes place without stopping the engine. When operating on natural gas, the unit's normal output is 9,341 kWe, while the engine output is reduced to 6,995 kWe (75%) to maintain a safe knock margin when operating on LPG, which has a methane number of 34. An engine such as the Wärtsilä 34SG-LPG could also be used with pilot fuel injection in a dual-fuel configuration, so that it can be used for marine propulsion. An important benefit would be the compliance with Tier III NO_x standards without the need for EGR or SCR systems. In principle, the 34SG engine could also be marinized, but it will not have the fuel flexibility of a dual-fuel engine.

An alternative option offered by Wärtsilä to utilise LPG for propulsion is the installation of a gas reformer to turn LPG and steam into methane in a mixture with CO₂ and some hydrogen. In this case, the energy content of the gas produced in the reformer is sufficient for a regular gas or dual fuel engine to be used with no need for derating. A reformer will, however, lower the efficiency. It is stated to reduce the efficiency in the chemical reactions by 2% and an additional 7% is transferred to low temperature water, whereas steam for the process can be generated by waste heat recovery from exhaust gases. However, when faced with a large variation in the fuel composition, e.g. for volatile organic compounds in shuttle tankers, this is a feasible solution. The gas reformer also allows the fuel gas quality and methane number to be improved by treating only a split of the feedstock and mixing it back into the main stream, thereby saving cost and space. Wärtsilä gas reformers received approval in principle from DNV GL for shuttle tankers in 2015.

“LPG is affordable and easy to handle; it can be stored in pressurized tanks, is easily accessible across all terminals in the world, and is more environmentally friendly than other fossil fuels. If you look at an engine running on LPG, it will have quite low CO₂ emissions as it has short molecules — mostly propane and butane. It also has no methane slip and is great for controlling greenhouse gas emissions, too.”

Kaj Portin, General Manager, Research & Technology Programs at Wärtsilä

3.2.3. Low speed engines(<300rpm)

These usually very large two stroke diesel engines are primarily used to power ships, although there are a few land-based power generation units as well. They can have power output up to approximately 85 MW (114,000 HP), operate in the range from approximately 60 to 200rpm and are up to 15m (50ft) tall, and can weigh over 2,000 short tons

(1,800t). They typically use direct injection running on cheap low-grade heavy fuel, also known as bunker C fuel, which requires heating in the ship for tanking and before injection due to the fuel's high viscosity. Large and medium marine engines are started with compressed air directly applied to the pistons.



Low-speed engines dual fuel (diesel/gas) are used prevalently in merchant shipping. These engines are utilised for the propulsion of all types of deep-sea ships world-wide, such as oil and product tankers, bulk carriers, car carriers, general cargo ships and container ships.

Low-speed marine diesel engine, the Wärtsilä RT-flex82T version B main engine Wärtsilä

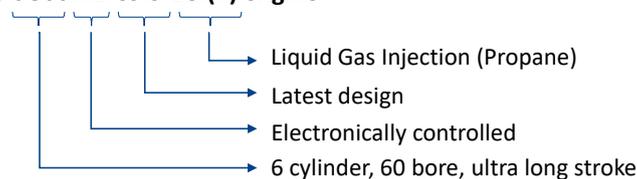
MAN ES - ME-LGIP engine

MAN ES, engine manufacturer, developed and is offering a commercially available engine in that field.

ME-LGI(P) Main engine general

- ▶ Engine cycle: two-stroke
- ▶ Number of cylinders: five to 12 depending on bore size
- ▶ Bore: 500 mm to 950 mm
- ▶ Stroke/bore ratio: 3.6 to 5.0

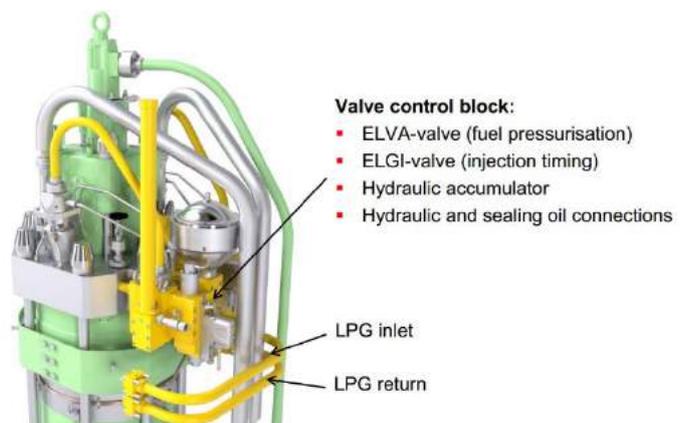
The main engine is a MAN ES 6G60ME-C9.5-LGI(P) engine



The engine, running according to the standard diesel cycle, have been built by the MAN ES Licensee CMD with smooth change-over between compliant fuel and LPG fuel. LPG is supplied to the engine as a liquid at 50barg and 45°C

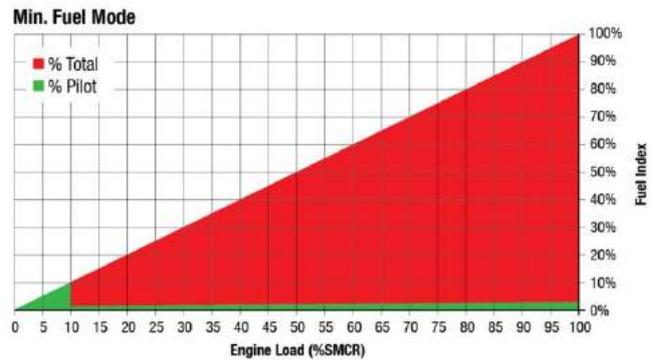
Main engine modifications

- ▶ Other type of cylinder cover, to house the gas fuel valves
- ▶ Additional gas control block, to control the LPG injection in the cylinder
- ▶ LPG injection valve (x2) (Fuel booster Injection Valve), to pressurise and supply the LPG
- ▶ Additional gas piping, double walled to bring the LPG to the gas fuel valves
- ▶ Sealing oil pumps, sealing oil prevents pollution of the hydraulic oil, used to build up the injection pressure with LPG
- ▶ Upgrade of the control system, to cope with the additional equipment



Main engine operating range

- ▶ LPG is supplied on medium pressure and injected as a liquid on high pressure
- ▶ Any combination of propane and butane can be burnt with an ethane content up to 25%
- ▶ About 3% of pilot fuel (compliant fuel oil) is required for the ignition.
- ▶ At low rpm, only pilot fuel will be burned
- ▶ is necessary because at lower rpm the LPG injection valve cannot be controlled sufficiently due to inertia of the valve
- ▶ During manoeuvring, the engine will switch automatically between “pilot fuel only” mode and LPG mode



Benefits at a glance

- ▶ Meet current and future SOx regulations
- ▶ Lower total cost of operation
- ▶ Switch between HFO, MGO or LPG with no performance loss
- ▶ Efficient and reliable low speed, two stroke engine
- ▶ Simple retrofit solution



Fuel consumption at part load optimization

- ▶ Same heat rate on fuel oil and LPG
- ▶ 80% MEP derated engine at 65% load:– G60ME-LGIP: 155 g/kWh – G50ME-LGIP: 154 g/kWh

MEP and speed derating

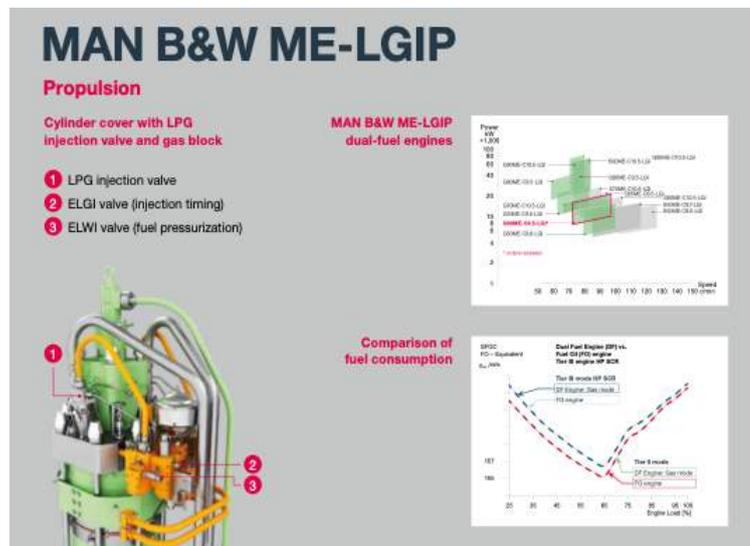
- ▶ G60ME-LGIP: 56% power derating possible
- ▶ Multiple choice of engine size and number of cylinders to match optimum propeller design and power

Compliance with emission regulations

- ▶ IMO Tier II
- ▶ IMO Tier III with SCR, EGR or EcoEGR for improved efficiency when operating in Tier II mode

Main features

- ▶ **Turbocharging system:** High efficiency constant pressure turbocharging systems with MAN, ABB or MHI turbochargers as standard
- ▶ **Engine automation and control** In-house developed gas safety and control system
- ▶ **Fuel oil system:** Common injection system for pilot oil and for main injection
- ▶ **Gas system:** LPG injection by fuel booster injection valves (FBIV)



- ▶ **Tolerant to many different LPG compositions**

Auxiliary systems

- ▶ Gas supply conditions: circulation with supply at 50 +/- 2 bar and 25-55 deg. C

MCR = Maximum Continuous Rating SCR = Selective Catalytic Reduction SFOC = Specific Fuel Oil Consumption

An overview of the fuel tank, fuel supply system and engine, as well as the piping is given in Figure below.

The Low Flashpoint Fuel Supply System (LFSS) takes the fuel from the service tank and boosts its pressure to the engine supply pressure, which ensures that the fuel remains liquid and that no cavitation occurs until it reaches the fuel booster injection valve. The flow of fuel should at all times be higher than the engine's fuel consumption.

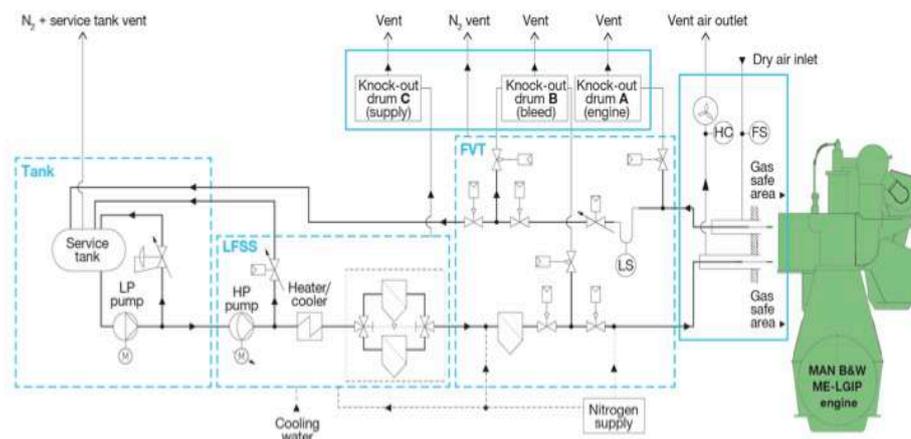
To ensure the fuel delivery temperature, a heater/cooler is placed in the circulation circuit.

The fuel valve train connects the fuel supply system with the engine through a master fuel valve. For purging purposes,

the valve train is also connected to a nitrogen source. Typically, the valve train will be placed outside the engine room above the weather deck to improve safety. From the valve train, the fuel is fed to the engine in a double-walled ventilated pipe through the engine room.

The new MAN B&W ME-LGIP Engine

ME-LGIP auxiliaries – sequences of operation



The system is monitored by hydrocarbon sensors (sniffers). If LPG vapour is detected inside the double-walled pipe, the safety system will switch to fuel oil operation smoothly and without any loss of power.

Advantages

- ▶ LPG-fuelled engines experience safe and reliable running with comparatively low maintenance costs while gas valves and gas pipes are smaller but similar to those of the well-known ME-GI engine.
- ▶ The Liquid ME-LGI engine uses liquid gas for injection all the way from tank to engine and non-cryogenic pumps can be used to generate the required pressure, comprising standard, proven equipment readily available from many suppliers within the LPG industry.
- ▶ Operation on LPG seems also to solve the logistics problems that LNG has at this time since LPG, in principle, is accessible over almost all the planet. Furthermore, cryogenic technology is not required, which makes LPG auxiliary systems less expensive compared with LNG.
- ▶ By introducing LPG as fuel to the dual-fuel GI system, substantial emission benefits can be obtained, especially with regard to SOx, PM and CO2. NOx emission reductions and IMO Tier 3 targets can be achieved if LPG operation is combined with either an SCR or EGR system.
- ▶ In the case of an ME-LGIP engine designed to run on LPG, the dual-fuel capability offers the owner or operator

the opportunity to shift between HFO and LPG in accordance with price changes and varying emission controls and regulations, depending on where the ship is trading.

Green Ship Future project

The **Green Ship of the Future Project** undertook a retrofit study for a 38,500 dwt tanker powered by a low-speed diesel engine which was planned to spend 13.5% of its time in an environmental control area. Three options were considered: the use of low sulphur fuel; placing an exhaust gas scrubber in the system or using LNG as a fuel. The low sulphur fuel option introduced some lubrication issues. The exhaust scrubber alternative, based on using heavy fuel oil after 2015, required a new funnel layout due to the introduction of the scrubber together with its associated machinery and new tanks. In the latter case, the LNG fuel usage required new piping and a fuel supply system together with new LNG tanks;

in this case, two 350 m³ tanks mounted on deck. The associated costs, based on industry quotations, for these last two options were estimated at 5.84M US\$, 50% of which was for the scrubber and auxiliary machinery, and 7.56M US\$ respectively. In the LNG case, the tanks and machinery conversion were estimated at 4.38M US\$ with 40 days' off-hire time. In contrast, the scrubber option required an estimated 20 days' off-hire time. More favourable economics for LPG compared to LNG would be expected, due to lower retrofit implementation.

Example

BW Gemini has been retrofitted with pioneering LPG dual-fuel propulsion technology



The world's first VLGC BW Gemini has successful complete sea trials.

The vessel was retrofitted in 2020 with Wärtsilä's ground-breaking LPG Fuel Supply technology. This is the first of 15



BW LPG ships to be retrofitted for operating on LPG fuel with MAN dual fuel engine and the Wärtsilä system. BW Gemini has achieved a historic milestone as the world's first VLGC to be fuelled by LPG, with the retrofitted main engine running on LPG and switching to traditional fuel seamlessly.

The retrofitting process at Yiu Lian Dockyard in Shenzhen, China, took approximately 60 days

and is estimated to have emitted 2,060 tons of carbon dioxide. This is approximately 97% lower when compared to ordering a newbuilding with similar technology.

Hartmann chooses MAN dual-fuel engines for new LPG tankers

MAN Energy Solutions has won the contract to supply individual MAN B&W ME-LGIP liquid gas injection LPG dual-fuel engines to three new 5,000 cbm LPG tankers being built for Hartmann Gas Carriers, part of Germany's Hartmann Group.



The ships are currently under construction at CIMC Sinopacific Offshore & Engineering Co., Ltd. (CIMC-SOE) shipyard in Shanghai. Each newbuilding will receive a propulsion package featuring one 5S35ME-LGIP engine with an Alpha controllable pitch propeller, power take-off (PTO), and a propulsion control system (PCS). MAN Energy Solutions also expects to introduce its new Triton control platform

with the engines. MAN Energy Solutions' two-stroke licensee, CMD, will construct the engines in Lingang, China with delivery scheduled for the second half of 2021. The contract contains an option for two further vessels.

3.2.4. Electric Motors (with LPG power generators)

The electric propulsion system consists of a prime mover which may be of two types:

- ▶ Diesel driven
- ▶ Turbine or steam driven

Both the systems produce less pollution as compared to conventional marine propulsion system, which involves burning of heavy oil.



Electric motors offer a modern solution with less pollution as compared to conventional marine propulsion systems, that involve burning traditional fossil fuels. Power for motor propulsion is supplied by the ship's generator(s) and prime mover assembly. Configurations involving electric motors as main propulsion system are often called also Hybrids. Hybrid propulsion facilitates flexible system solutions.

For all vessels with electric propulsion the power plant is essential. The power plant consists of several medium speed gas/diesel engines, which drive the electrical generators. These engines that drive the generators could very well be LPG fuelled engines. The generators are connected in a common grid, to the main electrical switchboard. All loads, including propulsion, thrusters, auxiliaries, and ship systems are normally fed from this grid, and the total load is shared between the running generators. The configuration of the power plant is based upon total installed power, operating modes, flexibility and redundancy requirements, and equipment cost. The number and rating of power generating sets must be optimised to achieve the desired flexibility in view of fuel economy for prime movers, operational profile and service factor. The purpose is to achieve optimal loading of the running generator sets during the different operation modes.

In the past electrical propulsion was used only in small vessels but now shipping companies are adopting this system for larger vessels and bigger size cargo vessel as well.

Electrical propulsion is particularly advantageous for:

- ▶ Tug and trawlers
- ▶ Dredgers
- ▶ Dynamic positioning vessels
- ▶ Cable laying ship
- ▶ Ice breakers
- ▶ Research ships
- ▶ Floating cranes
- ▶ Vessels for offshore industries



Case studies (the same technology could also apply with LPG)

- ▶ Gaz de France built the first two 154,000 m³ LNG carriers with ABB electric propulsion drive system, which consist of propulsion motors, frequency converters, propulsion transformers and medium voltage (MV) switchboards. The vessels are being built at Chantiers de l'Atlantique, one of the pioneering yards with respect to innovative propulsion systems and technical solutions.
- ▶ One small LNG carrier with electric propulsion is already in operation. The 1100 m³ LNG carrier "**Pioneer Knutsen**" was delivered from the Dutch yard Bijlisma in March this year, and has been in operation along the Norwegian west-coast since then. The main propulsion consists of two x 900 kW azimuth thrusters driven by low voltage frequency controlled motors delivered by ABB. Power production is generated by two x 900 kW Mitsubishi gas engines and two x 640 kW Mitsubishi diesel engines. The gas engines are fuelled by BOG while the diesel-engines are supporting with additional power if required.
- ▶ Finnish engine maker Wärtsilä has signed an agreement with Eidesvik Offshore to install a hybrid system with batteries on board of the latter's LNG-powered vessel Viking Princess. Viking Princess would become the first offshore supply vessel in which batteries reduce the number of generators on board. Depending on the ongoing task and weather conditions, the engine load varies between 90% and 20%. The new energy storage solution replaces one of the vessel's four generators and can provide balancing energy to cover the peaks, resulting in a more stable load on the engines. The technology keeps the engine load from dipping and re-routes the surplus to charge a battery, which in turn can fill in when needed.

3.2.5. LPG Range extenders

A **range extender** is a thermal engine, preferably LPG fuelled, driving a power generator that provides power to charge the batteries of an electric motor, to extend the range of the initial charge of the batteries. The batteries of range extender systems are initially charged at the vessel's marine base before commencing the trip.

The latest generation of range-extenders has been developed using hi-tech variable speed generators, that work in an optimized area of speed, but are very different than the common "gen-set" running a fixed speed (1500 rpm for 50 Hz – 1800 rpm for 60 Hz) that are currently the great majority on the market.

Range extenders sit in a complex and rapidly evolving power environment, but they are usually designed to operate at near constant load and torque for optimal efficiency and life. LPG range extender power may therefore be constant at all times or most of the time and it will deliver lower carbon emissions than petrol and provide the capability to increase a ship's battery-only range. Battery also experiences fast charging, which is on demand when stationary.

Examples

Motor manufacturer Torqeedo presented three new electric products in 2017. The equipment was debuted at the U.S. trade at the Electric and Hybrid Marine World Expo Florida Conference and Exhibition, in January 2020, and to the public at the Miami International Boat Show, in February 2020.



BMW's i3 high-voltage battery has been adapted to work with Torqeedo's 40-hp or 80-hp Deep Blue systems. It benefits recreational and commercial boat owners with its very high energy density, lower cost and safety standards.

The 25-kW range extender was specifically designed to efficiently power Torqeedo's Deep Blue system. It is the first inverter generator capable of supplying electricity for yachts and supporting serial hybrid systems. The

combustion engine, that could be retrofitted with LPG, runs at its most efficient operating point, supplying the full 25 kW regardless of fluctuating load demands or the voltage level of the Deep Blue batteries. It doesn't require a separate starter. Instead, it uses the electric motor included in the genset. This means reduced pollutants, less vibration and a longer life for the motor.

Torqeedo's Cruise FP fixed pod motor is a true alternative to an inboard diesel engine. Overall winner of the 2016 DAME Design Award, the integrated system features new electronic throttles and a modern, state-of-the-art user interface on a high-resolution marine display. It can be charged from shore power, solar, a generator or through hydro-generation while underway.

Hyperdrive, a UK company that specialises in developing electric vehicle tech, has created a small, modular petrol engine that could be converted to LPG and be added to EVs to increase range and mitigate range anxiety. It calls the range extending engine the Range Extender. The Range Extender is a single-cylinder 15kW (20hp) petrol engine that is designed to act as a generator for an EV's battery pack to increase range. It works on a 15kW, single-cylinder diesel version that will be ready soon and should be even more efficient.

3.2.6. LPG Reformer

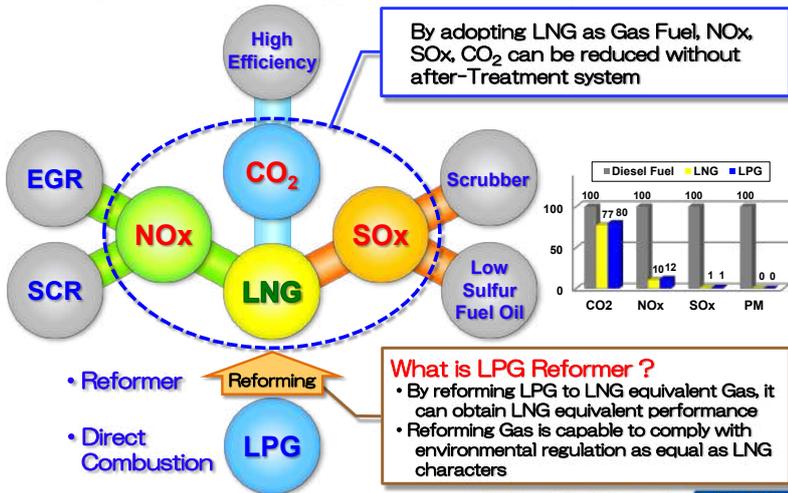
Japanese technology firms Osaka Gas and Daihatsu Diesel received an Approval in Principle (AIP) from ClassNK for their joint project on an LPG Reformer for marine engines. This was the first AIP granted in Japan for such equipment.

The LPG Reformer is designed to convert LPG into synthetic methane gas equivalent to the kind found in LNG, ClassNK

explained. Due to being mainly composed of propane and butane, LPG is susceptible to knocking (abnormal combustion), making it difficult to use as a fuel for lean burn gas engines and dual fuel engines. In contrast, by converting LPG into synthetic methane gas with the LPG Reformer prior to fuelling the engine, the risks of knocking can be restrained, resulting in equivalent operational performance observed when using LNG.

Additionally, using LPG as fuel can reduce the emission of environmentally harmful substances like SOx and NOx, compared to when using conventional heavy oil fuel, especially in line with the IMO's 2020 sulphur cap.

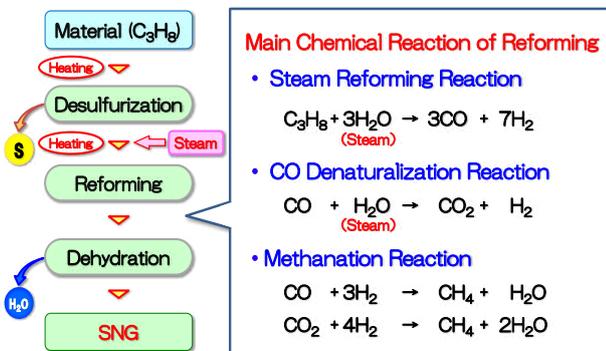
Compliant Technology for Marine Engines



M/GD 2019技術セミナー 2019.11.07

DAIHATSU DIESEL MFG. CO., LTD. DAIHATSU

Principle of LPG Reformer

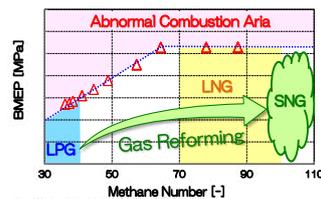


M/GD 2019技術セミナー 2019.11.07

DAIHATSU DIESEL MFG. CO., LTD. DAIHATSU

Measures for Using LPG as Marine Fuel

Combustion Type		Operation Performance
Direct Combustion Use LPG Directly	Gas Injection	<ul style="list-style-type: none"> • No Load Limitation • After-Treatment is Necessary to Satisfy IMO Tier 3 of NO_x Emission by Gas Mode Operation
	Premixed Lean Burn	<ul style="list-style-type: none"> • Limitation of Engine Load (Methane Number of LPG is Lower than LNG)
Reformer Reforming LPG to SNG	Premixed Lean Burn	<ul style="list-style-type: none"> • No Load Limitation (Methane Number of SNG is over 65) • SNG can be Easily Manufactured by Reforming



※ SNG : Synthetic Natural Gas

※ Methane Number (MN) is Anti-Knocking Index of Gas Fuel (MN : High → Knocking : Low)

※ Daihatsu Diesel's Dual Fuel Engine Compatible with City Gas 13A (Methane Number : 65)

DAIHATSU DIESEL MFG. CO., LTD. DAIHATSU

3.3. Marine LPG Engine Types

Fuel system technologies are key in engine development. The technology around fuel delivery in gasoline and diesel engines has developed significantly over the years. Consequently, such technologies, also related to the use of LPG as an engine fuel, have evolved and several such advanced systems are currently present in the market. However, not all are equally applicable to marine engines.

Natural gas engines have been used for many years both on land and aboard ships. While there is a limited choice of marine LNG engines with power ratings below 1,000 kilowatts (kW), numerous options exist for engines above this rating, and these are commonly used on merchant vessels.

On the contrary, LPG engines are used for recreational crafts and fishing boats in many places around the world. The ready supply of high-powered LNG engines means the availability of commercial engine technology is not a barrier to the use of LPG as a marine fuel for many types of engines.

There are three basic types of LNG engines that can easily be converted to LPG:

- ▶ **Lean burn, spark-ignition**, pure gas types operating on the Otto cycle and using a spark plug to ignite the gas/air mixture in the combustion chamber. Manufactured by companies such as Rolls-Royce Marine/Bergen, Mitsubishi and Hyundai, they range in power from around 300 kW to 9,700 kW.
- ▶ **Dual fuel with diesel pilot engines operating on the Otto cycle** and using natural gas together with a second fuel source, which may be distillate or heavy fuel oil. They allow the operator flexibility in deciding which fuel to use, based on price and availability. Manufacturers include MAN, Wärtsilä, Caterpillar/MAK, ABC Diesel and Electro Motive Diesel. They range in power from around 700 kW to 17,500 kW.
- ▶ **Direct injection with diesel pilot engines operating on a diesel cycle**, with natural gas injected directly into the cylinder near the top of the compression stroke. Conversion of an existing diesel engine requires limited modification to the engine itself, so this type of engine offers a higher potential for retrofitting existing units for direct injection operation. At present, no medium- or high-speed marine engines are available in this category, but slow-speed engines are, that now can deliver up to 42,700 kW.

Currently, there are limited examples of large LPG marine engines from engine manufacturers.

Examples of LNG engine engines that could easily be developed to use LPG

Lean burn prechamber spark ignited engine from Mitsubishi (low pressure Otto cycle) used in:

- ▶ Ferry Glutra
- ▶ Knutsen Pioneer LNG tanker
- ▶ Coast guard vessels



Lean burn prechamber spark ignited engine from Rolls Royce (low pressure Otto cycle)

- ▶ Ferries delivered in 2007 (Bergensfjord, Stavangerfjord, Mastrafjord, Raunefjord, Fanafjord)
- ▶ New RORO project Sea-Cargo
- ▶ 7500 m3 LNG coast tanker

3.3.1. Otto petrol/LPG bi-fuel engine

This is one of the largest categories in the **outboard marine engines segment** particularly due to their use in the small boat segment. Bi-Fuel petrol-LPG engines exist in the market only as conversions from existing petrol engines. Most LPG conversions today, especially in outboards engines, involve petrol fuelled spark- ignition engines, which are particularly well suited to run on LPG.

Otto Gas engines with their homogeneous combustion generally have low NOx emissions and high efficiency and will typically comply with the IMO Tier III limits without exhaust after-treatment. However, they require a certain stability of the fuel gas against self-ignition (“knocking”, as expressed by the methane number MN) and they must be carefully developed in order to keep un-burnt gas (“LPG slip”) to a minimum. In an Otto engine, the fuel-air mixture will not ignite until a spark is created. The compression ratio is much lower (typically 1:10) compared with 1:17-18 for compression ignition (diesel).

3.3.2. Otto LPG Mono Fuel engine

Spark Ignition dedicated mono LPG fuelled engines operate much like petrol marine engines. The primary advantage of these engine is that they use 100% LPG as fuel. Without additional gasoline systems onboard, they are mainly used as outboard engines in small boat applications that carry only one type of fuel and there is no need for a second fuel delivery system.

Such engines had been developed earlier in Europe, the US and elsewhere, and had found their use mostly in the leisure sector.

Spark-ignited LPG engines (“LPG only”) with either carburettors or port injection of LPG. These are “single-fuel” engines and must meet special redundancy requirements for marine applications.

3.3.3. Dual-fuel Diesel/LPG engine (diesel engine with direct LPG injection)

Dual fuel diesel/LPG engines are normal diesel engines, that can be converted to dual fuel engines because they have relatively the same compression ratio, structural design, etc.

Dual fuel (DF) engine works as an ordinary diesel engine in diesel mode and as a pilot ignited Lean burn gas engine (low pressure Otto cycle) in the gas mode.

Examples include:

- ▶ Gas supply vessels Viking Energy, Stril Pioneer, Viking Queen and Viking Lady (Wärtsilä DF)
- ▶ LNG tankers France and Korea (Wärtsilä DF, MAN Diesel DF)
- ▶ FPSOs

Dual fuel diesel engines have the advantage that the power of the engine can be increased by adding a few more cylinders and hence there is no limit for the size of the ship. These will always need a certain quantity of diesel fuel for running even in gas mode, but on the other hand they may also run on 100% liquid fuel (diesel- or HFO), i.e. dual fuel capability.



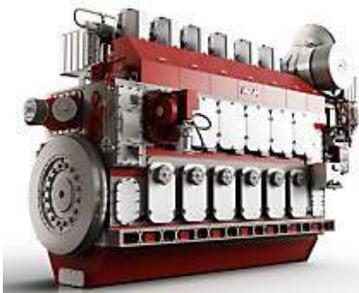
The fuel LPG is directly injected at high pressure into the cylinder after the diesel pilot fuel has ignited. This is also known as “Diesel DF principle” or the “GD-principle”, such engines have dual fuel capability and may also run on 100% liquid fuel (diesel-or HFO).

The diesel gas engines have diffusion burning which ensure good capability of burning gases with low knocking stability (“low MN”) and at the same time producing low UHC emissions (“LPG slip”). However, they require a gas system and additionally exhaust after- treatment (EGR, SCR) is needed to comply with IMO Tier III NOx emission limits.

All diesel engines in LNG carriers are slowly changing over to dual fuel diesel engines because of the advantages of the gaseous fuel resulting from the vaporized liquefied natural gases in tanks during sailing.

Example: Caterpillar dual fuel CAMAK engine

After commercialisation of diesel engine dual fuel retrofit conversions, Caterpillar Marine is underway on another dual fuel engine retrofit conversion on board the 472 foot Fure West tanker. The MaK M 43 C diesel engine on board the tanker will be retrofitted in hull to the seven-cylinder M 46 dual fuel platform, with each cylinder offering 900 kW of rated power. Additionally, Caterpillar is also supplying the complete gas system for the tanker, including bunker stations, two LNG tanks measuring 4.15 meters by 24 meters and the vaporiser. This project, backed by the European Union will mark the second MaK engine dual fuel retrofit. In 2014, Caterpillar successfully completed the dual fuel engine retrofit conversion on the Anthony Veder Coral Antheia LNG carrier.



The M 46 dual fuel engine was designed for electric drive propulsion systems as well as mechanical propulsion systems. Although designed for unlimited operation on LNG, marine diesel oil and heavy fuel oil, the M 46 DF will reach industry-leading efficiency in gas mode. The M 46 DF was strategically engineered to allow for the retrofitting of current M 43 C engines. Additionally, existing M 32 E engines can be retrofitted to the MaK M 34 DF dual fuel platform. As a result of the synergies between the two platforms, Caterpillar can perform in hull retrofit conversions without having to move the engine block or perform extensive machining.

Example: Wärtsilä marine Dual Fuel engines



Wärtsilä 20DF



Wärtsilä 31DF



Wärtsilä 34DF

The DF version of engines are compact units that extend the dual-fuel technology benefits to cover the entire power range. The



Wärtsilä 40DF

Wärtsilä dual-fuel engine capability enables ships to be operated on either conventional liquid marine fuel (LFO, HFO or liquid bio fuel) or LNG. The switch between fuels can be made seamlessly without loss of power or speed. Such fuel flexibility enables compliance with



Wärtsilä 50DF

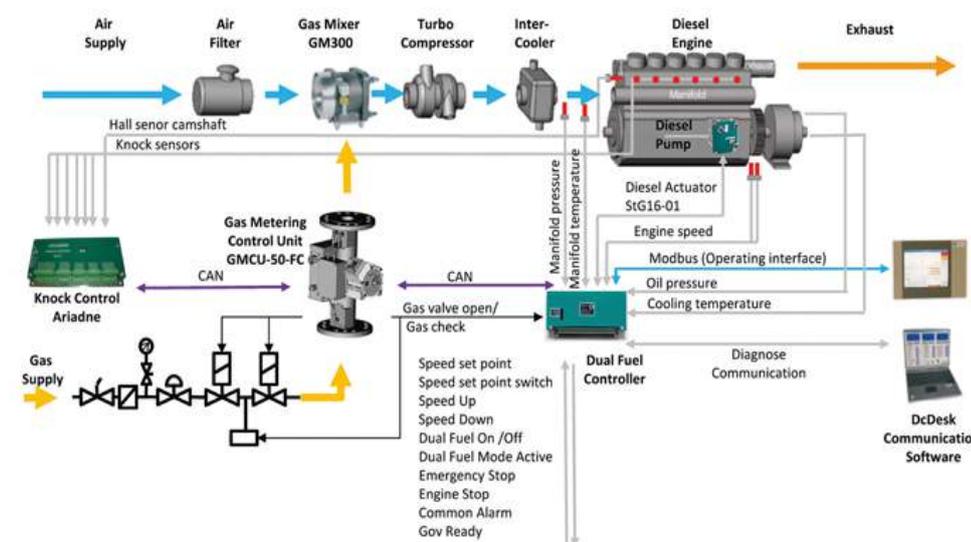
emission regulations in controlled areas, while giving operators the option of determining the fuel according to cost and availability.

Example
Dual-fuel Engine by Anglo Belgian Corporation and HEINZMANN

As a sophisticated solution for marine applications, engine manufacturer Anglo Belgian Corporation and system supplier HEINZMANN have been developing a special dual fuel engine for ships with direct propulsion. For this project, diesel engines optimised for dual fuel operation were used. These optimisations enable conversion rates of steady state 95 % to be achieved (95 % gas / 5 % diesel).

The key challenges for the engine management system are the variable speed/load and the fact that the torque/power output of the engine is not known. Maintaining a high conversion rate in dynamic operation calls for sophisticated control concepts. In addition, rapid switching functions back to 100 % diesel are used, for example to prevent misfires due to insufficient pilot injection.

A gas metering control unit is used to control the gas mass flow rate. The gas flow rate provides a similar linear relationship to the power output as for the diesel level. This enables the diesel and gas power produced to be calculated and the engine to be protected against overload.



The diesel side of their engine is powered by a mechanical injection system which is connected to an electric actuator. The figure provides a schematic view of the system.

In dual fuel mode, this diesel controller is still responsible for the actual speed/power control. An additional control loop then controls the optimum gas quantity. This enables the diesel injection system

to respond dynamically to rapid fluctuations or step changes. If the load is disconnected, the engine can quickly be switched back to pure diesel operation. This prevents the diesel level from falling below the minimum required for combustion and thus causing misfires.

A key factor for dual fuel use is protecting the engine against overload. In a fully optimised and utilised system, both the diesel injection system and the gas system (with a small diesel proportion as pilot fuel) can handle almost the entire engine load. When combined, the engine can easily be overloaded. In generator applications, the load signal from the generator management system is then used as a limit. However, in directly powered ships, there is no such torque/load signal. Therefore, the dual fuel control unit determines the power generated by the diesel and gas fuels dynamically during operation. To calculate the power generated by the diesel fuel, the power depending on fill level and speed is recorded on the test bench and plotted in a characteristic map.

To record the power generated by the gas, a gas flow metering unit is used, which uses a differential pressure measurement to determine the gas flow and can control it using a throttle valve. The gas data (density and calorific

value) can be used to calculate the gas power from the gas flow. The dual fuel controller transmits this data along with a gas power set point.

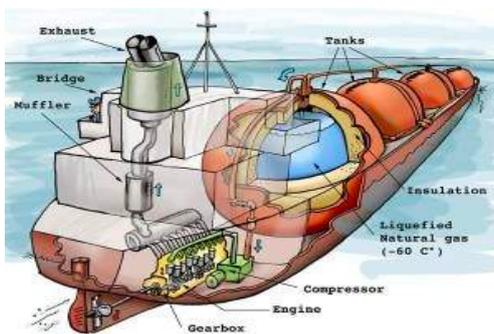
The total power that the engine delivers at the crankshaft is calculated from the actual gas power and the diesel power. As the gas quality will fluctuate according to the gas types in the different ports, a facility has been provided for specifying the gas quality using the visualisation unit. A conceivable scenario would be that an engineer receives a measuring report for the gas when refuelling and has to enter the corresponding quality. Otherwise, a corresponding safety factor would have to be maintained.

3.3.4. Diesel – ignited LPG engine

Diesel-ignited gas engines with conventional low-pressure gas feed but with ignition by the injection of a certain quantity of diesel fuel, also known as the “Otto DF” or “low pressure DF” principle. The fuel LPG is directly injected at high pressure into the cylinder after the diesel pilot fuel has ignited. This is also known as “Diesel DF principle” or the “GD-principle”, such engines have dual fuel capability and may also run on 100% liquid fuel (diesel-or HFO).

3.3.5. Gas fuel or Tri-Fuel Propulsion

LNG fuel is now utilised to be burnt in the Main Engine after adopting some modification in the propulsion engine to reduce emission from the ship. It is known as tri fuel because it can burn gas fuel, diesel and heavy fuel.



The tri-fuel engine technology is already present in the marine market and is mainly used for LNG ships with marine diesel oil, heavy fuel oil, and liquefied natural gas (LNG) used together as marine fuels. This concept was introduced by Wärtsilä and MAN for gas carrier ships.

The same technology is going through research and development for using the tri-fuel engine in container ships. The first implementation of such engine is under process on a 7300 TEU container ship undertaken by Wärtsilä. The new gas ignition auxiliary engines will be installed in this

ship which will run on tri-fuel technology.

LNG (LPG could be similar used) for Auxiliary engines

Container ships do not carry gas cargo in bulk hence, unlike gas tankers, they do not have enough supply of gas fuel. In contrast, a small tank for LPG fuel storage can supply enough gas fuel in port to auxiliary engine of a container ship.

The auxiliary engine of such system is provided by conventional fuel supply i.e. MDO and HFO along with LNG/LPG supply when in port to comply for the emission norms.

Just as used in the dual fuel engine of MAN B&W, safety precautions are also taken to supply gas to the injection system of the engine. Pilot fuel injection i.e. MDO is used for initial ignition as auto ignition temperature of natural gas is very high i.e. 580 degrees centigrade.

LPG Storage

The LPG can be installed in the ship itself to store LPG fuel along with all required bunkering arrangements and pipelines, so that it can be supplied to the generators when in port. Two basic methods can be adopted for storing LPG. LPG cylinder containers or LPG storage tank.

Advantages of Tri-Fuel Engines

The LNG/LPG fuel for container ship has following advantages:

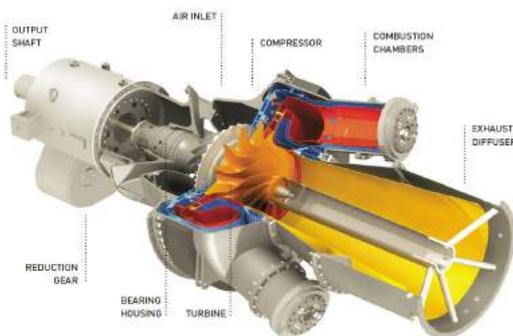
- ▶ Use of expensive shore power can be eliminated.
- ▶ LNG/LPG is cheaper and cleaner fuel than marine gas oil.
- ▶ Ships' generator sets can be used to remove voltage and frequency constraints of shore supply.
- ▶ Shore electric supply is not available globally although LPG is available everywhere.
- ▶ No need to install additional and costly exhaust gas cleaning system.
- ▶ The LPG fuel offers lowest emission levels of CO₂, NO_x and SO_x.
- ▶ The operating and investment cost is less compared to other means of reducing emissions.

3.3.6. LPG Gas turbine

Turbine Engines – Turbogenerators

Gas turbine engines – in comparison with reciprocating engines – have some advantages that favour their use amongst others. Such advantages, especially in comparison with diesel engines, include:

- ▶ Better use at low temperatures due to the rapid start-up possibilities.
- ▶ Significantly lower heat transfer through the engine oil and lack of liquid cooling system, which significantly reduces the number of vulnerable assemblies and essentially lowers power losses through the cooling system.
- ▶ Significantly less maintenance and repairs.
- ▶ Reduced amounts of oils and lubricants required to operation.
- ▶ Mild torque characteristic, without pulsation typical for reciprocating engines.
- ▶ Significantly lower weight and size compared to reciprocating engine.



However, some features of gas turbine engines, mainly higher specific fuel consumption and higher costs have been restricting their wider use. Major companies have been involved in modification of such engines and their application in hybrid electric power systems. These engines are used mostly in stationary power generating units in turbogenerator applications.

Many warships built since the 1960s have used gas turbines for propulsion, as have a few passenger ships, like the jetfoil.

Gas turbines are commonly used in combination with other types of engine. Most recently, RMS Queen Mary 2 has had gas turbines installed in addition to diesel engines. Because of their poor thermal efficiency at low power (cruising) output, it is common for ships using them to have diesel engines for cruising, with gas turbines reserved for when higher speeds are needed. However, in the case of passenger ships the main reason for installing gas turbines has been to allow a reduction of emissions in sensitive environmental areas or while in port. Some warships, and a few modern cruise ships have also used steam turbines to improve the efficiency of their gas turbines in a combined cycle, where waste heat from a gas turbine exhaust is utilised to boil water and create steam for driving a steam turbine. In such combined cycles, thermal efficiency can be the same or slightly greater than that of diesel engines alone; however, the grade of fuel needed for these gas turbines is far costlier than that needed for the diesel engines, so the running costs are still higher.

Recently, a Memorandum of Understanding was signed with GE in South Korea to cooperate with South Korean and

global partners on an LPG-fuelled ferry design, using a combined cycle gas turbine, electric and steam (COGES) system (see also case study under 3.5.4.2). GE is offering turbines in the LM2500 family for maritime applications, with technology based on turbines used in aircrafts for decades. These turbines are now available to burn LPG as a fuel without changes to the fuel injection system. The LM2500 family can provide turbines with an output of 22–33 MW and 36-38% efficiency in single-cycle mode. The minimum load on the gas turbine is 50%. A gas turbine can be combined with either a steam turbine to increase the efficiency to 53–55% or a CO₂ turbine, which GE has recently started to offer.

Hybrid turbocharger

Lately, the maritime sector has been investing heavily in R & D to cut down harmful emissions from the ship, along with reducing fuel consumption and operating cost. Maritime market has seen several developments in the past mainly for developing waste energy recovery systems such as economiser, turbocharger etc.



A marine technology innovation has taken the research to all new level and to a step ahead. **It is called the Hybrid Turbocharger.**

The hybrid turbocharger is developed by Mitsubishi heavy industries and it differs from conventional turbochargers in terms of both waste recovery and fuel saving. Exhaust gas energy is recovered to turn the compressor, which supplies scavenge air to the main engine and also generates electricity through an alternator attachment incorporated in the turbocharger known as MET hybrid turbocharger. The turbine and compressor does the heat energy recovery work and the alternator is used to generate electrical power without consuming any extra fuel as it is driven by the shaft power of the turbocharger.

Turbine engines are rarely used on commercial ships. Part of the reason is that gas turbines are generally costly and less efficient than diesel engines and therefore are less suited for commercial use. The same goes for spark ignition (SI) engines. Steam turbines are extremely fuel flexible, but are also slow starting. Furthermore, they require a rather steady load in the high band, which is why they are not common.

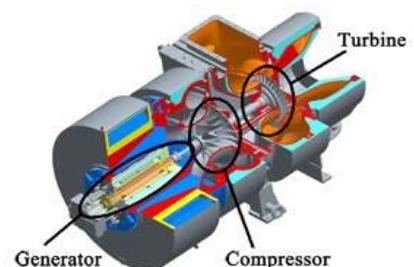


Many cruise ships often have diesel-electric plants where a large bank a diesel generators or gas turbines provides power for everything on the ship, including propulsion. The motors connected to thrusters that can be rotated 360 degrees to help steer the ship and make tight turns.

Turbine-Electric Plan for Cruise Ship

Advantages

- ▶ With only little increase in the dimensions, enough power can be generated from main engine operation.
- ▶ Fuel savings the heat recovery system is used for driving the alternator.
- ▶ The generator can function as motor at low load operation to drive blower for maintaining scavenge air pressure of the main engine.
- ▶ Eliminates the installation of an auxiliary blower for the main engine. As no extra fuel is used, it helps cut vessel emissions.



Example

MV Shin Koho, a 292 m long 180,000 dwt bulk carriers with a draft of 24.5m is the world's first merchant vessel to successfully equipped with the hybrid turbocharger technology.

3.3.7. LPG Outboard engine, mono fuel or bi-fuel

In the outboard marine engine sector, LPG has made its appearance the last few years, either through aftermarket

Propane Engines & Propane Conversion.

- LEHR EnviroGard Designs, Certifies, and Manufactures both Propane Engines and Propane Conversion Kits
- Focus on General Purpose Engines from 1hp – 50hp
- Typical applications include lawn mowers, floor polishers, construction equipment, outboardmotors.
- Exceed EPA & CARB Emission Standards.
- Full Engine Warranty.



conversions, or as OEM (original equipment manufacturer) alternatives manufactured by LEHR, in sizes up to 40HP with bigger models also in development. LEHR is the world's first OEM to manufacture outboard engines that run exclusively on LPG. These are single fuel engines suitable for sea water with components made of high-quality stainless steel with high reliability to resist galvanic corrosion and chemical resistance to salt water. Originally developed as four-stroke engines, LEHR recently launched a lower cost LPG two-stroke engine as a direct alternative to the low-cost kerosene and gasoline two-strokes.

The benefits of LPG to the marine industry are numerous and substantial, no gasoline polluting the water, virtually eliminated particulate emissions that turn into methyl mercury in the water, the available power of internal combustion engines without the environmental detriment of gasoline, extended engine life and

reduced cost of operation LEHR's introduction of outboard engines bring all the advantages of LPG into the primary vessel propulsion segment, opening the world of LPG to a much larger audience.

Examples

PROPEL outboard engine

Propel (erstwhile known as LEHR) offers the world's first LPG powered line of **marine outboard engines**. As the most awarded LPG propane company in the world for this, **Propel** utilises a patented technology, which ensures that it's marine products are greenest and most reliable engines on the market today. Propel offers following 2.5HP, 15.0HP outboards.



the cleanest,
5.0HP, 9.9HP,

Tohatsu outboard engine

Tohatsu America Corp. introduced new 5-hp LPG outboard. Compared with gasoline, LPG exhausts 12 % less carbon dioxide, which makes it a cleaner option for boaters. Added safety features include fuel regulators, shut off valves and the necessary LPG fittings to ensure safe operation. The proprietary Safety Fuel shut-off valve keeps propane fuel from continuously running when engine is not in use. Tohatsu claim the new LPG outboard will run for a full five hours at WOT on a single 11lb tank with no reduction in performance.

Mercury outboard engines

The 5hp Propane Four Stroke sports an easy-to-reach **shift lever** on the engine and has **six tilt positions** with a shallow-water drive to set the outboard where it is needed. The so-called **Sail Power** model is designed for boaters who use a small outboard to pilot their **sailboat**, and it has some additional features:

- ▶ 20-inch (508 mm) or 25-inch (635 mm) shaft lengths.
- ▶ 12 Volt, 4 Amp / 50-Watt alternator charging system with cable in order to charge a battery to run electronics or lights.
- ▶ Reverse-thrust exhaust relief and high-thrust propeller for slow-speed handling and control.



Facts about pollution for outboard engines

Idling speed

- ▶ Two-stroke engine carburetors are undoubtedly the most polluting, both at idling and maximum speed.
- ▶ Four-stroke engines have less HC emissions (-87% compared to two-stroke engines), but have higher emissions compared to LPG - powered engines (+137,5% compared to an LPG powered engine and +52% compared to an LPG powered engine tested with enriched gas mixture).
- ▶ LPG-powered engines guarantee the lowest unburned hydrocarbons emissions (-95% compared to two-stroke engines and -42% compared to four-stroke gasoline engines/-92% and -34% compared to LPG engines)

Top speed

- ▶ Two-stroke engine carburetors are still very polluting even though emissions from an engine running at top speed are 50% less compared to one running at idle speed.

Compared to two-stroke engines, four-stroke engines have a better combustion rate and fewer emissions when running at higher speeds (-91% compared to two-stroke engines). Nevertheless, they still pollute significantly more than an LPG fuelled engine (on average, almost twice as much). The EFI electronic injection system has improved its performance and lowered dangerous emissions for both the two-stroke and the four-stroke engine range. An EFI four-stroke LPG powered engine running at full speed ensures the lowest emissions (-95/94% compared to a two-stroke fuel injection engine and -48/36% compared to a four-stroke gasoline powered engine).



An LPG Outboard Engine

▶ It is greener

In recent years, increasing environmental regulations have led to the development of cleaner burning gasoline-powered outboard motors. But, in terms of their environmental sustainability, nothing has revolutionized the outboard engine market like the advent of LPG-fuelled motors. LPG outboards burn fuel 50 times cleaner than even eco-friendly gasoline-powered outboards. They release very little in the way of greenhouse gases or toxic fumes. In fact, some LPG-powered outboards have zero emissions.

▶ Easier to Start and Run More Smoothly

Because propane fuel is pressurised, LPG outboards start more easily. There is no need to prime or choke the engine. And, because LPG is naturally high in Octane (over 100), when you move the throttle, you'll find a wide range of power.

▶ **No Need for Fuel Additives or Winterisation**

Although it is not easy to find an LPG station at the dock, LPG offers significant benefits over gasoline as a fuel for outboard motors. There is no need to use additives, mix fuel or pour gas. LPG comes in its own canister. Even better, unlike gasoline, LPG does not contain ethanol and won't degrade over time. That means there is no need to winterise the fuel tank or worry about how fresh the fuel is. Also, as LPG fuel systems are closed, there is no need to worry about water infiltrating the tank.

▶ **Fuel Economy and Reduced Maintenance**

The other benefits, aside from only having to carry one fuel source, are low emissions, fuel economy and reduced maintenance which is important in often remote locations where fuel related issues can occur. The "Propane" as it will be known will retain all the standard features of the petrol MFS5C which features large carry handle and front mounted shift level. The through propeller exhaust reduces noise.

3.4. Ship propulsion

Besides, the type of the engine, the way the engine is integrated in the propulsion system of the vessel creates various ship propulsion systems. Nowadays in the shipping industry we can find wide range of different propulsion systems such as dual-fuel steam turbine mechanical (DFSM), dual-fuel diesel electric (DFDE), dual-fuel gas turbine electric (DFGE), dual-fuel diesel mechanical (DFDM) or i.e. diesel mechanical propulsion with reliquefaction (SFDM+R), electric hybrid configurations etc. Some companies are building hybrid ships that are able to run on both oil and gas as fuel. The technology will see ships to be powered by natural gas for up to half way through the voyage and still be capable to switch over to bunker fuel for the remainder of the journey. Ideal will be to use natural gas or LPG as the primary source of power and bunker fuel as a secondary/emergency one.

There are a **few configuration options for LPG-fuelled vessel technology**. Each of these engine propulsion options can be designed, or is designed, to burn natural gas or LPG. For each option mentioned below, LPG is stored on the vessel as LPG.

The first LPG-fuelled configuration is a vessel that is powered by **marine gas turbines or gas engines**. These gas turbines or gas engines can be combined with steam turbines; a combined gas turbine and steam system is referred to as COGES. A marine gas turbine can be designed to burn natural gas, but is historically designed in the marine industry to burn other liquid fossil fuels. Marine gas turbines, with the appropriate fuel purification systems, can burn fuels on the spectrum from jet fuel to heavy fuel oil.

The second option is a **hybrid diesel-gas vessel**; these vessels have separate diesel engines and marine gas turbines or gas engines. The systems are referred to as Combined Diesel Electric and Gas (CODLAG) and Combined Diesel and Gas (CODAG) systems. If the system employs gas turbines, the turbines can be designed to burn natural gas, as in the case of COGES.

The third vessel type is powered by a **dual fuel diesel electric (DFDE) engine**. This engine type is designed to burn both diesel and natural gas. The Dual Fuel Diesel Electric (DFDE) propulsion system for marine vessels combines diesel and steam technology for an engine that can be powered either by diesel fuel or LPG stored on the vessel, as well as “boil off” gas in the case of LPG refrigerated carriers.

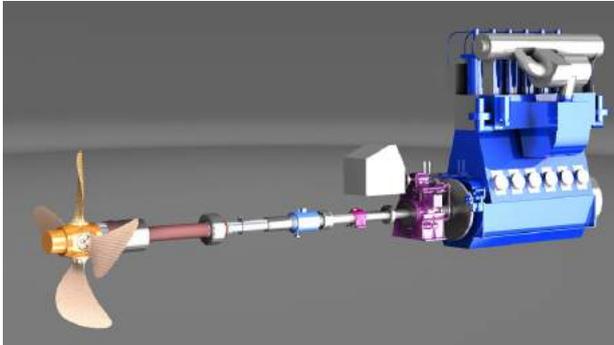
Wärtsilä, one of the manufacturers of DFDE engines, terms these engine operating functions as “gas mode” and “diesel mode” There are two operating modes for the dual fuel (DF) engine: gas mode and diesel mode. The natural gas operating mode of the DF engine is low pressure with a diesel injection for the pilot. The diesel operating mode of the engine is with diesel injection.

DFDE is more thermally efficient than a steam turbine by 15% and reduces daily fuel consumption by 30-40 tons compared to a steam engine (Ragas). The DFDE system is not to be confused with the Combined Diesel Electric and Gas (CODLAG) and Combined Diesel and Gas (CODAG) systems.

The CODLAG and CODAG systems, while sometimes referred to as dual- fuel systems are inherently different from a DFDE system. Namely, the CODLAG/CODAG systems incorporate separate diesel and gas turbines or gas engines on the same vessel; these systems do not have a single engine that can bunker both diesel and natural gas, besides diesel serving as a pilot fuel for a gas engine designed to burn natural gas. Hence, the DFDE systems are inherently more flexible than the COGES, CODLAG, and CODAG systems that have engines that are tied to burning a specific fuel. The benefit of burning only one fuel (whether it is diesel or natural gas) is the simplification of bunkering, as only a single fuel needs be bunkered. There is a higher initial capital cost for a ship propulsion LNG-fuelled system compared to a diesel engine. LPG-fuelled systems require new equipment not aboard typical diesel-powered vessels including a large, gas combustion unit (RasGas). LPG-fuelled systems are a proven technology with many operating hours.

3.4.1. Direct Drive

Direct drive propulsion systems are the most commonly used systems for larger tankers, bulkers, container and vehicle carriers. Direct drive propulsion system is an invariable choice for low-speed diesel engines and has a very basic



arrangement with one or two cross-head main engines with direct drive with a fixed propeller and the speed of the engine (90-105 rpm) is also the speed of the propeller. It consists of a propeller, which is connected to the main engine with the help of the shaft. Manoeuvring of the ship is done by controlling the speed of the main engine and by changing the direction of rotation of the propeller. The thrust block in this design forwards the energy from the propeller into the hull and not into the engine. This is a simple and efficient design.

Initially this system was used in almost all ships. In case of a geared drive propulsion a reduction gear is used in the main shaft which connects the propeller. The propeller can change its pitch according to the requirement.

3.4.2. Hybrid, Parallel

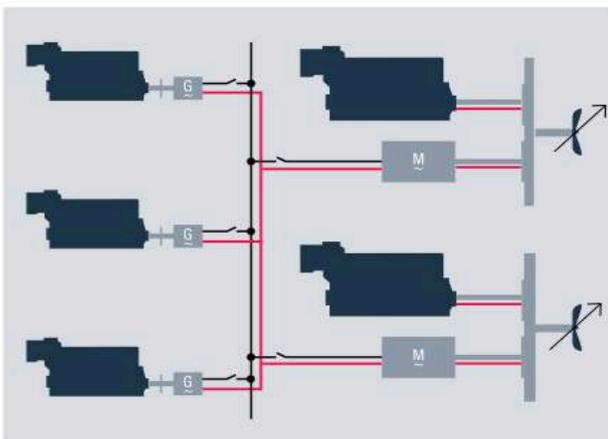
Operation of a hybrid parallel propulsion system

Mechanic and electric power work together in the propulsion train, optimising the propulsion efficiency for ships with a flexible power demand. The combination of mechanical power, delivered by diesel engines, and electrical power, provided by electrical motors, delivers propulsion power, which assures the ship a broad operational capability, providing the right amount of power and torque to the propeller in each operation mode. Whereas a diesel-mechanic propulsion system is often designed according to its maximum power demand, which, for example, is fitted for a tanker or cargo vessel according to the most hours of the operation profile, a hybrid propulsion plant is better prepared for changes in operation during the vessel's trip or even the vessel's lifetime.

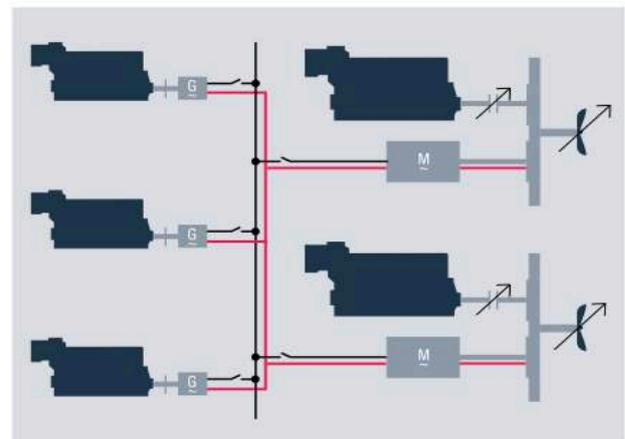
Hybrid propulsion systems can be differentiated between configurations, where the diesel engines and the E-motors work in parallel on the propeller (CODLAD), or where either the diesel engine or the E-machines are used (CODLOD).

CODLAD (Combined Diesel-Electric and Diesel Engine)

CODLOD (Combined Diesel-Electric or Diesel Engine)



Example: Passenger ferry using a PTI-booster in case of the need for additional power



Example: Navy vessel using electric propulsion for slow sailing speeds

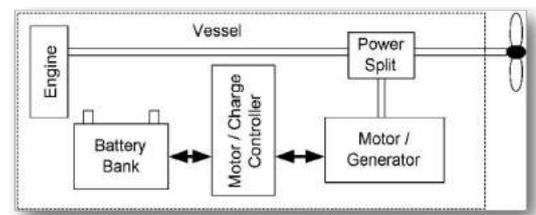
Hybrid-electric systems include an internal combustion engine, generator, battery, and electric motor, typically allowing the diesel, gasoline or LPG engine to do the heavy work when needed, and charge the electric system and allow it to respond to lighter loads such as low-speed cruising or providing power for lights and electronics. The advantages of all-electric or partial-electric boats are the reductions in pollution, noise, vibration, and potentially, cost.

Marine hybrid systems include an internal combustion engine (ICE), a generator, an electric storage unit, and an electric motor. As mentioned before, diesel electric systems are different from hybrids because they produce power using a diesel generator that supplies power directly to an electric motor. In a hybrid system, there is an electric storage element in the system.

In a parallel hybrid system (Figure), both the ICE and the electric motor are able to provide power to the propeller. The motor/generator can either drive the propeller with energy from the battery, or be used to charge the battery. Fewer batteries required than series hybrid system.

Suitable for:

- ▶ Canal boats.
- ▶ Sport fishing boats when trolling.
- ▶ Trawler yachts.
- ▶ Motor sailing sailboats.



The advantages of a parallel hybrid propulsion system

- ▶ Flexible use and highest efficiency.
- ▶ The propeller can be driven by the diesel/LPG engine, and/or by the electric motor, resulting in a highly redundant and reliable propulsion system.
- ▶ Part-load in a conventional system.
- ▶ Part-load in an electrical system.
- ▶ In hybrid mode, the diesel/LPG engine and the propeller can operate with variable rpm (combination mode) and the network frequency and voltage is fixed and stable.
- ▶ Reduced plant operating costs due to the possibility to operate the main engines and auxiliary gensets in a range where the required amount of power is provided by a combination of engines which run near or at their optimal loading with their minimal specific fuel oil consumption.
- ▶ As a result of high plant efficiency over a wide range of operation modes, not only fuel oil consumption is lower, but fuel related emissions like SO_x and CO₂ are also reduced. Further pollutants are reduced as there is less incomplete combustion that intensively occurs in the low-loaded engines.
- ▶ In E-mode with variable-speed E-motors less noise is caused and pressure side cavitation on the propeller is reduced, as it can be operated at an optimal speed/pitch ratio. Propeller speed and pitch can be controlled independently. Additionally, the underwater noise signature can be reduced. This especially offers benefits at slow speed sailing.
- ▶ Depending on the operational modes of the vessel the main engines and the auxiliary engines run less hours per year and, when in operation, on higher loads. Both lead to less required maintenance.
- ▶ Large variation of operation modes appropriate for a flexible power demand, for slow speed operation up to boosting. This results in an optimal overall plant operational capability with fast system responses and a high plant flexibility.
- ▶ While mechanical optimisation is often determined by one or a few operational modes, the electrical drive capability tremendously increases flexibility. "Off-designs" for hybrid propulsion systems are fewer compared to pure mechanical system designs.

Disadvantages of the System

- ▶ Lower overall energy efficiency for ships running at full-rated speed all the time due to losses.
- ▶ Higher initial capital cost.
- ▶ Different and improved training for ship's crew as the system is completely different from mechanical system and involves major automation.

Hybrid-Electric Propulsion Technology for Small Vessels

Electric propulsion is not a recent innovation however it has become the “standard” propulsion solution in many applications, especially when it comes to specialised vessels. High redundancy and reliability of the propulsion plant, improved manoeuvrability of the ship and lower fuel oil consumption due to an optimised loading of the engines is key.

Hybrid-electric systems include an internal combustion engine, generator, battery, and electric motor, typically allowing the diesel or petrol engine to do the heavy work when needed, and charge the electric system and allow it to respond to lighter loads such as low-speed cruising or providing power for lights and electronics.

The advantages of all-electric or partial-electric boats are the reductions in pollution, noise, vibration, and potentially, cost.

There are five vessel types that appear to be suited for hybrid-electric propulsion systems:

- ▶ In-shore fishing boats.
- ▶ Short distance water taxis.
- ▶ Short haul ferries.
- ▶ Yachts.
- ▶ Cruise boats.



Currently, there is limited market acceptance of hybrid-electric propulsion technology for small vessels, but there are a growing number of practical applications in use in the recreational and commercial boat industry. These early adopters will drive further development which, in turn will increase the number of viable applications.

- ▶ The viability of any configuration of hybrid-electric system on a small vessel is affected by three main considerations: economy, environment, and strategic. Depending on the application, economy may not be the deciding factor when choosing the most effective propulsion solution.
- ▶ To become more viable, hybrid propulsion technology needs better collaboration between designers of the main components: engines, motors, propellers. One example of this need is the technical challenge of matching the load performance of permanent magnet electric motors to propellers.
- ▶ Future developments in battery technology and integrated system controllers will significantly increase market acceptance and viability of hybrid systems in small vessels.
- ▶ For recreational boaters, lifestyle priorities will play a big part in the choice of using a hybrid system on board – even if it costs more than a traditional internal combustion engine system. The virtual elimination of noise, vibration and smell from using electric drive is worth the cost difference to some boaters.
- ▶ Two small vessel applications that are commonly seen in Nova Scotia, and elsewhere in the world, that show potential for viable hybrid systems are nearshore fishing boats and racing sailboats.
- ▶ Unlike an all-electric system, a marine hybrid system includes an internal combustion engine (ICE), a generator, an electric storage unit, and an electric motor. Diesel electric systems are different from hybrids because they produce

power using a diesel generator that is directly connected to an electric motor. In a hybrid system, there is an electric storage element in the system.

Pump transports LPG in hybrid marine propulsion systems

German pump manufacturer SERO Pump Systems integrated its side channel pump SHP marine into the secondary fuel supply system (SFSS) of hybrid ship propulsion units pumping LPG to the main shipboard engine.



The pump's technical features include a low suction head requirement, uninterrupted pressure-constant delivery of low-viscosity liquids and a resistance to shipboard vibrations, ensuring high functional reliability of SHP marine in 'over the water' applications.

SERO said SHP marine is capable of meeting all technical challenges (low net positive suction head requirement, reliable and pressure-constant delivery of volatile LPG and resistance to vibrations from the ship's hull) when pumping LPG from the

storage tanks through the SFSS feeding the main engine of an oceangoing vessel.

The SHP marine model can be used for both low pressure or high-pressure requirements depending on the SFSS design used and the manufacturer claims it is the first pump of its kind to be both Lloyd's Register accepted and DNV GL type-approved for marine dual-fuel propulsion systems.

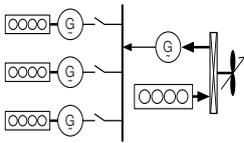
LPG fuel supply pumps

- ▶ Both the LP and HP supply pumps are VFD driven side channel pumps.
- ▶ The pumps have very low maintenance requirements.
- ▶ These pumps can ensure a stable supply even with changing LPG characteristics thanks to the specific design which is a hybrid between positive displacement and centrifugal pumps.
- ▶ A high head ratio per stage at low flows can be achieved with excellent NSPHr and high tolerance to vapor content in the medium.
- ▶ An ideal match for the required flowrate with a pump head of 15~25 barg.



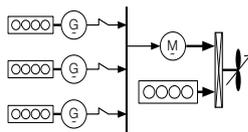
Hybrid Operation Modes

▶ Generator mode (PTO-mode)



The main engine provides not only the power for ship propulsion, it also supplies the electric power needed for the ship's consumers. This mode is selected for transit sailing. It allows a high loading of the main engine, running with low specific fuel oil consumption and therefore with minimal emissions. This often prolongs the maintenance period of the generation sets as they can be switched off when not needed.

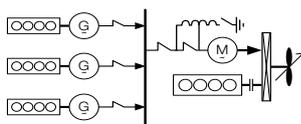
▶ PTI booster mode



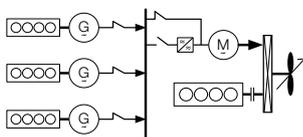
The PTI booster mode is mainly selected for maximum speed. Together with the main engine the electric machine works as an auxiliary motor, which delivers support to the propeller. The generation sets deliver the electric power, both for propulsion and the vessel's consumers. The PTI booster mode increases mainly the flexibility of the propulsion system for peak loads.

▶ PTO / PTH mode

For some types of vessels, like for chemical tankers, a redundant alternative propulsion system is recommended for emergency operation. In case of the main engine is not operating, the electric machine is used as a motor, which delivers the power for the propeller. The generator sets supply the propulsion power as well as the electric power for the vessel's consumers. To start the electric machine independently as a motor a starting device is needed.

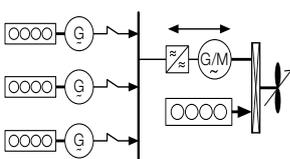


▶ a) Installed generator set capacity is much higher than the PTH-motor power rating ("Strong mains") An autotransformer unit is a common solution to start the PTH-motor from zero speed.



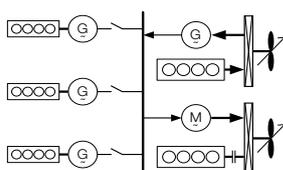
▶ b) Installed generator set capacity is in the same range like the PTH-motor power rating ("Weak mains") A smart solution for starting the PTH-motor is a small frequency converter, which can also be used to operate the propeller with variable speed at slow sailing. In parallel a circuit breaker is installed, which is closed for continuous PTH-operation with constant propeller speed or in PTO-mode.

▶ Hybrid mode



▶ The electric machine is used as alternator as well as propulsion motor (PTO/PTI). This opens the way for flexible use of the main engine and the generation sets. In electric/PTI-mode the propeller is driven with variable speed by a frequency converter. In PTO-mode the converter supplies a fixed voltage and frequency to the mains. The main engine and the shaft generator can operate in a range of 70% to 100% rpm. Doing so maximizes both propeller and engine efficiencies and also helps to reduce exhaust emissions.

▶ Electrical cross-connection mode (Electric Shaft)



▶ In case of a twin propeller application there is a possibility of driving both propellers with the power of one main engine supplying one shaft machine (PTO) and run the other shaft machine as "take-in-device (PTI)". This mode ensures a high loading of the running main engine as well as extra redundancy and flexibility to the complete propulsion system.

Examples of Hybrid propulsion packages are mentioned in Appendix 1.

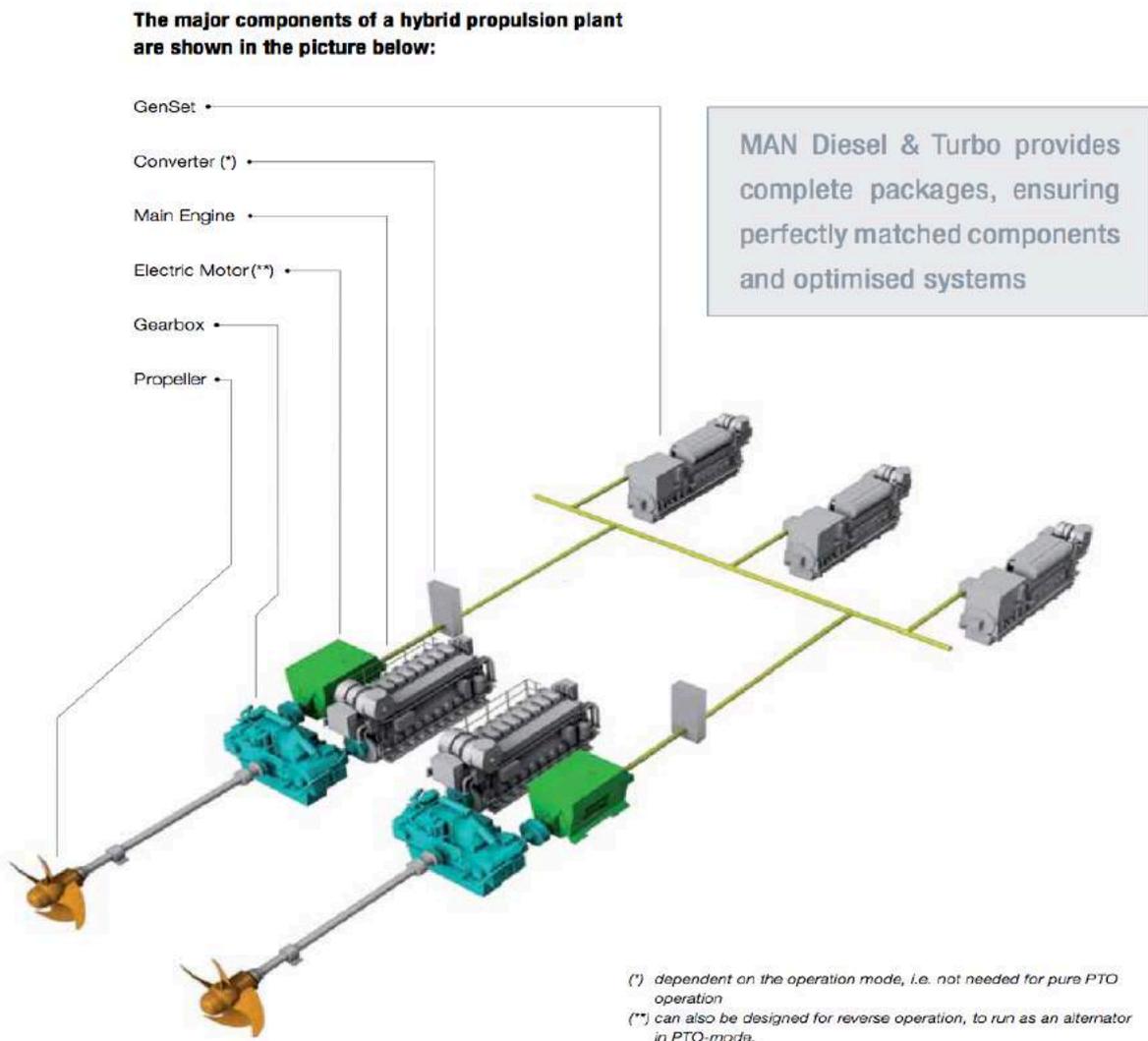
3.4.3. Hybrid, Serial

The main components of a diesel/LPG electric serial drive are the diesel/LPG generator(s), frequency inverters, propulsion motor, propeller, and controller. In a hybrid Serial system, there is an electric storage element in the system.

In a series hybrid setup, the electric motor is the only means of providing power to the propeller. The motor receives electric power from either the battery pack or a generator run by an ICE. This lets a vessel continue to operate even after the batteries are discharged.

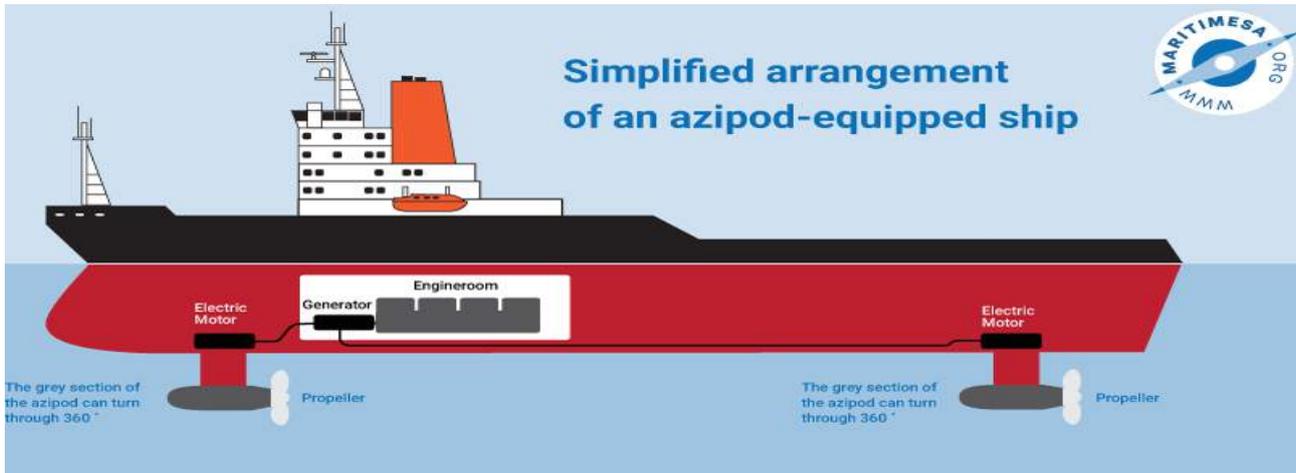
Sample Hybrid Propulsion Plant

Hybrid serial systems are particularly suited for:



- ▶ Canal boats.
- ▶ Sport fishing boats when trolling.
- ▶ Trawler yachts.
- ▶ Motor sailing sailboats.

EPROX: Energy-saving electric propulsion



EPROX is an innovative approach of a fuel saving electric propulsion system. It combines lowest possible fuel oil consumption with highest performance and flexibility of electric propulsion. Recent developments in DC-technology



and distributions and energy management enable the Diesel engines to operate at variable speed, meaning that the speed of the engine can be adjusted for the minimum fuel oil consumption according to the current system load. Another advantage is the integration of energy storage sources, like batteries. They reduce transient loads on the diesel engines and give a much better dynamic system response.

Such an advanced system could be also developed to use LPG as fuel.

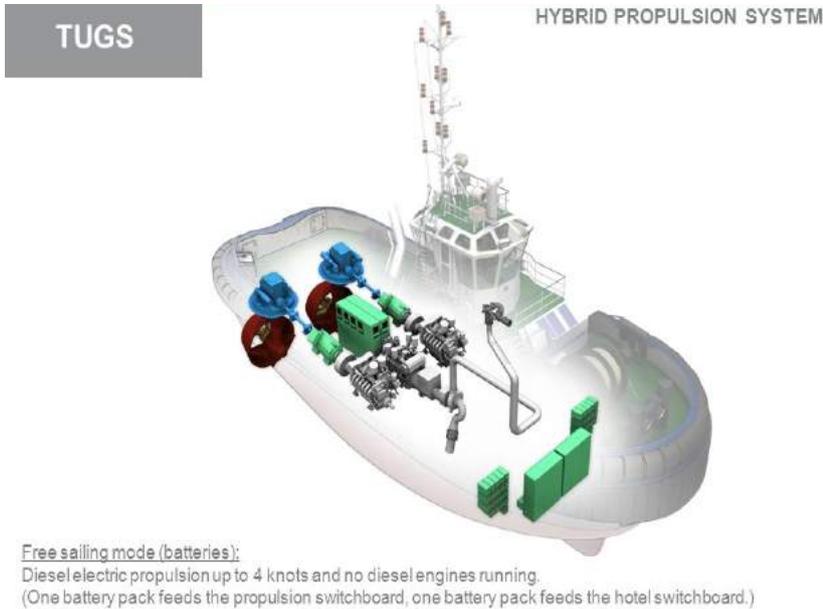
The advantages of the serial hybrid propulsion are:

- ▶ It is estimated that a reduction of about 30% volume is possible compared to the conventional mechanical drive system.
- ▶ Load diversity.
- ▶ Fuel savings. For ships spending more time at low speed, fewer engines can run at full power, resulting in greater energy efficiency and hence less fuel consumption. A navy ship may save an estimated 15–25% in fuel compared to a similar ship with mechanical drive.
- ▶ The lifetime cost saving from reduced fuel consumption may exceed the higher initial procurement cost of electrical propulsion.
- ▶ Greater manoeuvrability.
- ▶ Low noise. An electric motor is able to provide a drive with very low vibration characteristics and this is of importance in warships, oceanographic survey vessels and cruise ships where, for different reasons, a low noise signature is required.
- ▶ Higher automation. The electric propulsion system can be designed to be highly automated and self-monitoring, hence requiring less maintenance and fewer crew members to operate than with a mechanical drive system.
- ▶ Best complementation with the propeller.
- ▶ Economical part-load running.
- ▶ Low emissions.

3.4.4. Electric with “Range Extender” engine

Increasingly, there are series hybrids where the conventional combustion engine never drives the propulsion: it simply

charges the batteries. These engines are known as range extenders because they extend the range beyond what would be affordable with batteries alone. They are smaller than the combustion engines used in conventional marine propulsion and are simplified in some respects.



This arrangement is a hybrid drivetrain supplied from an electric energy storage. The most commonly used range extenders are internal combustion engines and identically represent the best optimising of the propulsion efficiency for ships with a flexible power demand. The electrical side

of all systems will be based on a direct current or an alternating current motor, coupled to the ship's propeller shaft, with the speed and direction of propeller rotation being governed by electric control of the motor itself or by the alternation of the power supply.

The advantages of the electric propulsion with the range extender are:

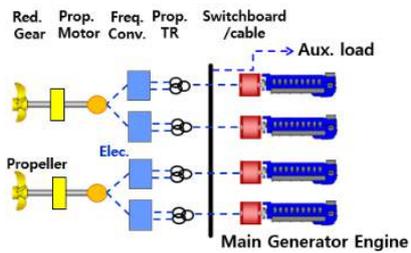
- ▶ It is estimated that a reduction of about 50% volume is possible compared to the conventional mechanical drive system.
- ▶ Load diversity.
- ▶ Fuel savings. For ships spending more time at low speed, fewer engines can run at full power, resulting in greater energy efficiency and hence less fuel consumption. A navy ship may save an estimated 30–35% in fuel compared to a similar ship with mechanical drive.
- ▶ The lifetime cost saving from reduced fuel consumption may exceed the higher initial procurement cost of electrical propulsion.
- ▶ Greater manoeuvrability.
- ▶ Low noise. An electric motor is able to provide a drive with very low vibration characteristics and this is of importance in warships, oceanographic survey vessels and cruise ships where, for different reasons, a low noise signature is required.
- ▶ Higher automation. The electric propulsion system can be designed to be highly automated and self-monitoring, hence requiring less maintenance and fewer crew members to operate than with a mechanical drive system.
- ▶ Economical part-load running.
- ▶ Low emissions.

3.4.5. Tri-Fuel Diesel Electric Propulsion (TFDE) Over Diesel Engine Propulsion

TFDE stands for tri-fuel diesel electric propulsion ships specifically for LNG carriers. Similar practice could be proved also successful for LPG carriers.

Examples

- ▶ Wärtsilä and Maran Gas Maritime signed a five-year agreement covering the maintenance of the latter's 21 TDFE (tri-fuel diesel electric) LNG carriers equipped with Wärtsilä 50DF engines. The Wärtsilä 50DF tri-fuel engines installed on the MGM vessels can be operated with heavy fuel oil (HFO), marine diesel oil (MDO) or natural gas.
- ▶ Pan Asia, the first of four 174,000m³ tri-fuel diesel electric (TFDE) LNG carriers that shipowner Teekay LNG has ordered from Hudong-Zhonghua Shipbuilding, has completed sea trials off the east coast of China



3.4.6. Outboard/Inboard engines

Outboard motors are self-contained engine units mounted to the rear wall (transom) of the boat. Each unit has an engine, propeller, and steering control. Cables attached to the steering wheel actually pivot the entire motor unit to provide steering.



Models can be powered either by LPG, CNG or gasoline or diesel fuel, and single or twin engines are available.

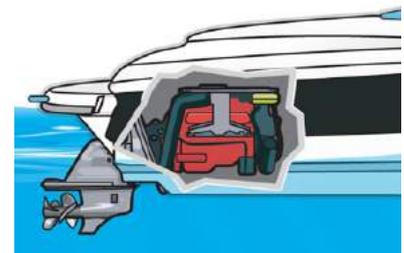
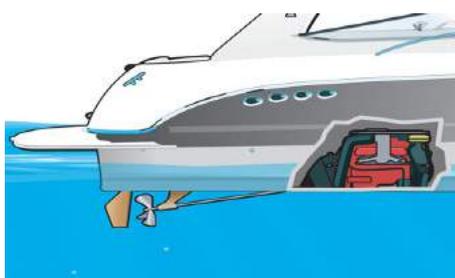
Most common is a rotating propeller, but some are jet-propulsion systems that move the craft by shooting water to push the boat.



Outboard motors are the most common type of boat propulsion, on freshwater fishing boats and pleasure craft. Inboard engines are mounted inside the hull's midsection or in front of the transom and apply similar technology like outboards. The engine turns a drive shaft that runs through the bottom of the hull and is attached to a propeller at the other end.

burn oil as a lubricant along with the fuel, and burn cleaner than conventional PWC engines.

Many personal watercraft (PWCs) have two-stroke inboard engines that New-technology two-stroke PWC engines are direct-injection engines



Stern Drives

Stern drives are known also as inboard/outboards (I/Os) because they combine features found on both inboard and outboard engines. Stern-drive engines adapted for marine use and are mounted inside the boat. A stern-drive engine is attached through the transom to a drive unit (also called an "outdrive") that is essentially the lower unit of an outboard. The engine turns a drive shaft that is attached to a propeller at the other end. Steering of stern-drive boats is controlled by the outdrive, which swivels like an outboard engine to direct propeller thrust. Stern drives have quieter and more fuel-efficient engines.

Jet Drives

- ▶ Jet drives propel a vessel by forcing a jet of water out the back of the vessel. Directing this jet of water steers the

vessel.

- ▶ Personal watercraft are the most common type of vessels that use a jet drive.
- ▶ Jet drives also may power larger vessels (jet boats) and are used commonly for vessels designed for shallow water conditions. Jet boats can have inboard or outboard jet drives. Jet drives use an engine to power a strong water pump, which sucks up water and then forces the water out the back to thrust the vessel forward.

All of the above engines could easily be converted to bi-fuelled petrol LPG or to be OEM mono fuel LPG Engines.

LPG Injection for Ship Diesel Engines

All diesel engines in LNG carriers are slowly changing over to dual fuel diesel engines because of the advantages of the gaseous fuel resulting from the vaporised liquefied natural gases in tanks during sailing.

Dual combustion engines are able to consume this gas and convert into useful energy. Normally during sailing the gas involved is completely used in these engines and the same engines use diesel as fuel during manoeuvrings in port.

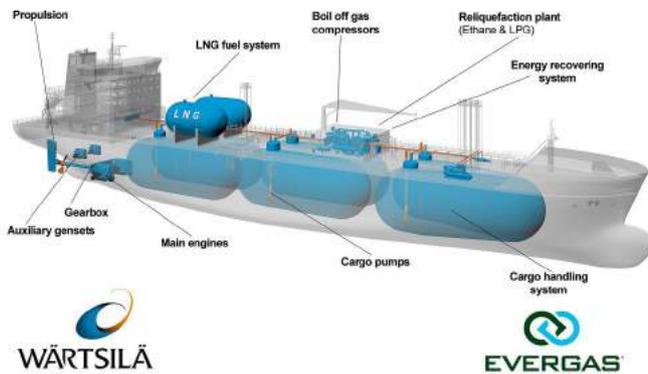
In LNG carriers where dual fuel engines are employed, the primary fuel is a natural gas (methane) and in LPG carriers the same practice could apply. These cargos which are being carried in these vessels can be used to operate on diesel engines. An additional advantage of the DFDE is it can operate on 100% diesel fuel also.

Initially when first LNG carriers were introduced the boil off gases from the tanks (i.e. propane) were used as fuel for power generation in boiler combustion. This boil-off gas rate will vary according to the quantity of LNG carried on board and the quality of the liquefied petroleum gas. It is approximately 0.12 to 0.16 percentage per day of ship cargo capacity. This boiled-off propane gas obtained from LNG tanks has a composition like methane, butane, and propane. Among this, propane has the greater proportion when compared to the other gases. Propane alone can contribute around 70% of LPG. But nowadays the same boiled off-gases are used in main propulsion diesel engines and for this purpose the diesel engines are changed over to dual fuel diesel engines thereby reducing the diesel consumed by the engine, hence reducing the overall operating cost of the ship as the daily fuel cost alone contribute to half of the daily running cost of the engines.

Normally during manoeuvrings inside congested waters, LPG injection is not efficient because it requires a steady service speed. So, during rough weather and in manoeuvrings periods the marine diesel or heavy fuel oil is used because it produces more power than propane injection. When the ship reaches sea speed or service speed, it is changed over to propane that will provide all the required sailing power during calm weather. These engines will operate completely on diesel and as the ship begins to sail at full speed the propane gas is admitted in the pilot injection valve to replace the diesel fuel to 80% or even more. Normal diesel engines can be converted to dual fuel engines because they have relatively the same compression ratio, structural design, etc. Dual fuel diesel engines have the advantage that the power of the engine can be increased by adding a few more cylinders and there is no limit for the size of the ship.

3.4.7. Ethane powered ship engine

Originally designed to run on LNG, MDO and HFO, the Dragon class vessels were meant to use LNG as fuel when trading ethane and other LPG cargoes. However, logistical challenges with LNG and extremely favourable price development of ethane led to the idea to use LEG cargo boil-off as fuel. Wärtsilä worked in close collaboration with Evergas and INEOS to make the world's first ethane-powered marine vessels a reality.



The overall solution has several competitive advantages for LEG carriers, including the ability to utilise HFO, MDO, LNG and/or LEG with uninterrupted operation; IMO Tier III compliance without the need for secondary exhaust gas treatment; low gas pressure requirements and the ability to effectively utilise boil-off gas from the cargo. Sulphur emissions are eliminated using LEG, resulting in a highly cost-effective means for Evergas to be compliant in SECA zones in both North America and Europe. Particulate emissions are also eliminated, enabling smokeless operation. The successful result of the project was enabled through strong collaboration between

Wärtsilä, INEOS and Evergas.

Mitsui Engineering & Shipbuilding Co. have completed the world's **first ethane-operated two-stroke diesel engine**. The engine is one of three the company is building to power three LEG (liquefied ethylene gas) tanker ships for Hartmann Schifffahrt of Germany and Ocean Yield of Norway. The ships are being built in China.

They have chosen ethane for different reasons:

- ▶ It is cheaper than HFO.
- ▶ It burns significantly cleaner.
- ▶ The most significant reason is that a tanker full of ethane can always tap into that ethane as fuel for the ship, should the need arise.

So far, eight of the ethane-powered engines have been ordered.

Mitsui Engineering & Shipbuilding Co., Ltd (MES) has completed the world's first ME-GIE ethane-operated two-stroke diesel engine. The engines will be for propulsion of three ethylene carriers, which primarily will carry liquid ethane as cargo. The Mitsui-MAN B&W 7G50ME-C9.5-GIE is the first engine in a series of three for installation in three LEG (liquefied ethylene gas) carriers of 36,000 m³ for Hartmann Schifffahrt of Germany and Ocean Yield of Norway, being built at Sinopacific Offshore Engineering (SOE) in China.

MAN Diesel & Turbo reports that ethane was chosen as fuel, in preference to HFO, due to its more competitive pricing as well as the significantly shorter bunkering time it entails. As a fuel, its emissions profile is also superior to HFO in which respect it is similar to methane and compared to HFO contains negligible sulphur and 15-20% lower CO₂. MAN Diesel & Turbo also verified methane operation on this engine type and states that the ME-GI engines will be set up such that they can easily be converted to run on methane as an alternative, as per the owner's wish. MAN Diesel & Turbo currently has eight ME-GIE engines on order.



While ME-GI engines have been designed for use by several, different fuel types to date, ethane is a new departure. Ethane is one of the natural-gas liquids (NGLs) that are naturally occurring elements found in natural gas (and frequently separated removed and sold as a separate product), and include propane and butane, among others.

3.4.8. Engines running on LPG could be converted to ammonia

MAN believes that in the future, engines running on LPG could be converted to ammonia combusting engines. As such, the most likely vessel candidates for ammonia-based propulsion would be ammonia carriers or LPG tankers due to the similarity of tank storage requirements. Aside from retrofits, MAN believes that it would even be possible to order an ammonia-ready engine design for LPG combustion.

Ammonia is gaining traction a true next generation fuel. One way of making shipping greener could lie with ammonia (NH₃). A pungent gas in its natural form, ammonia is widely used by farmers as a fertilizer and might seem an odd saviour for the shipping industry, especially as the manufacturing process is far from green. Ammonia is made by reacting nitrogen at high temperatures and pressures with hydrogen obtained from methane. The latter is an energy-hungry process, known as “steam methane reforming”, that accounts for 1.8% of all carbon-dioxide emissions.

However, according to new studies ammonia has a vital role as a zero-carbon fuel and energy store. The maritime industry is likely to be an early adopter of “green ammonia”, a fuel made by mixing nitrogen from the air with hydrogen obtained by electrolysis water using electricity from sustainable sources. Green ammonia could either be burnt in a ship’s engine or used in a fuel cell to produce electricity. Water and nitrogen are its only by-products and it has an energy content of 3 kWh per litre of fuel compared with just 2 kWh/l for liquid hydrogen.



Although conventional fuel oil has a higher energy content of 10 kWh/l, ammonia is easily stored in bulk as a liquid at modest pressures (10–15 bar) or refrigerated to –33 °C – making it an ideal chemical store for renewable energy.



Ammonia also benefits from a fully existing near global distribution network, in which it is stored in large refrigerated tanks and transported around the world by pipes, road tankers and ships.

Lloyds Register along with MAN, Samsung Heavy Industries and the MISC Group, announced plans to develop ammonia-fuelled tankers to deliver viable deep-sea zero-emission vessels by 2030. The UK’s Science and Technology Facilities Council has also been working on green-ammonia technology with three firms, Siemens, Engie and Ecuity.

Ammonia costs more than conventional fuels for ships. But if the power to create the hydrogen and ammonia can come from carbon-free sources, such as renewables or nuclear, then surely green ammonia will be the future of carbon-free shipping and other sectors too. When it comes to storing, ammonia can be stored on vessels under the same conditions as LPG, however, the tank volume would have to be twice that of LPG due to the lower energy density.

Major project to convert offshore vessel to run on ammonia- powered fuel cell

ShipFC consortium project has been awarded €10m fund injection to deliver world’s first high-power fuel- cell to be powered by green ammonia.

A maritime innovation project looking to install the world's first ammonia-powered fuel cell on a vessel has been awarded €10m funding from the European Union.

The ShipFC project is being run by a consortium of 14 European companies and institutions, co-ordinated by the Norwegian cluster organisation NCE Maritime CleanTech, and has been awarded backing from the EU's Research and Innovation Programme Horizon 2020 under its Fuel Cells and Hydrogen Joint Undertaking (FCH JU). The project will see an offshore vessel, Viking Energy, which is owned and operated by Eidesvik and on contract to energy major Equinor, have a large 2MW ammonia fuel cell retrofitted, allowing it to sail solely on the clean fuel for up to 3,000 hours annually. As such the project will demonstrate that long-range zero-emission voyages with high power on larger ships is possible.

The goal is also to ensure that a large fuel cell can deliver total electric power to shipboards systems safely and effectively. This is the first time an ammonia-powered fuel-cell will be installed on a vessel. A significant part of the project will be the scale up of a 100-kilowatt fuel cell to 2 megawatts. The fuel cell is tested on land in a parallel project and development and construction will be undertaken by Prototech. Testing will be executed at the Sustainable Energy Norwegian Catapult Centre. The ship-side ammonia system will be supplied by Wärtsilä. The ammonia fuel cell system will be installed in Viking Energy in late 2023.

LR awards AiP to ammonia-fuelled 23,000 TEU ultra-large container ship

LR has granted Approval in Principle (AiP) to Daewoo Shipbuilding & Marine Engineering (DSME) and MAN Energy Solutions for its ammonia (NH₃) fuelled 23,000 TEU ultra-large container ship design, a key result from a Joint Development Project (JDP) launched in 2020 focused on developing ammonia propulsion ships. It is the first AiP to be awarded in Korea for an ammonia-fuelled ultra-large container ship design.

As part of the JDP, DSME generated the basic design of the ammonia propulsion system and MAN Energy Solutions was responsible for the development and specifications of the ammonia dual fuel propulsion engine. LR's role was to review the suitability and risks of the design which involved a hazard identification (HAZID) workshop, a hazard & operability analysis (HAZOP) workshop and a design review in accordance with the Approval of Risk-Based Design (ARBD) process, which led to Approval in Principle.

LR's AiP certification is the first phase of the JDP. The second phase will involve further development of the design for meeting market demand in terms of commercial viability as well as technical and safety maturity. The ammonia-fuelled 23,000 TEU ultra-large container ship is expected to be commercialised by 2025.

MAN Energy Solutions has partnered with Japanese shipbuilder Imabari Shipbuilding, ClassNK classification society, Mitsui E&S Machinery, and energy trading firm of Itochu Corporation, Itochu Enex, on the development of a vessel powered by ammonia.

The cooperation builds on the work MAN Energy Solutions has already undertaken on the development of an ammonia-powered engine. This will serve as the groundwork for developing the design of the vessel including that of the ammonia storage tank, fuel supply system and a series of systems for the main engine. Mitsui and ClassNK will support the project through safety assessment services and insight, while Itochu Enex and Itochu Corporation will be in charge of exploring the ammonia fuel distribution network and establishment of a supply facility of ammonia for maritime use. The project is in line with the shipping industry's efforts to decarbonize shipping and build zero-emission vessels.

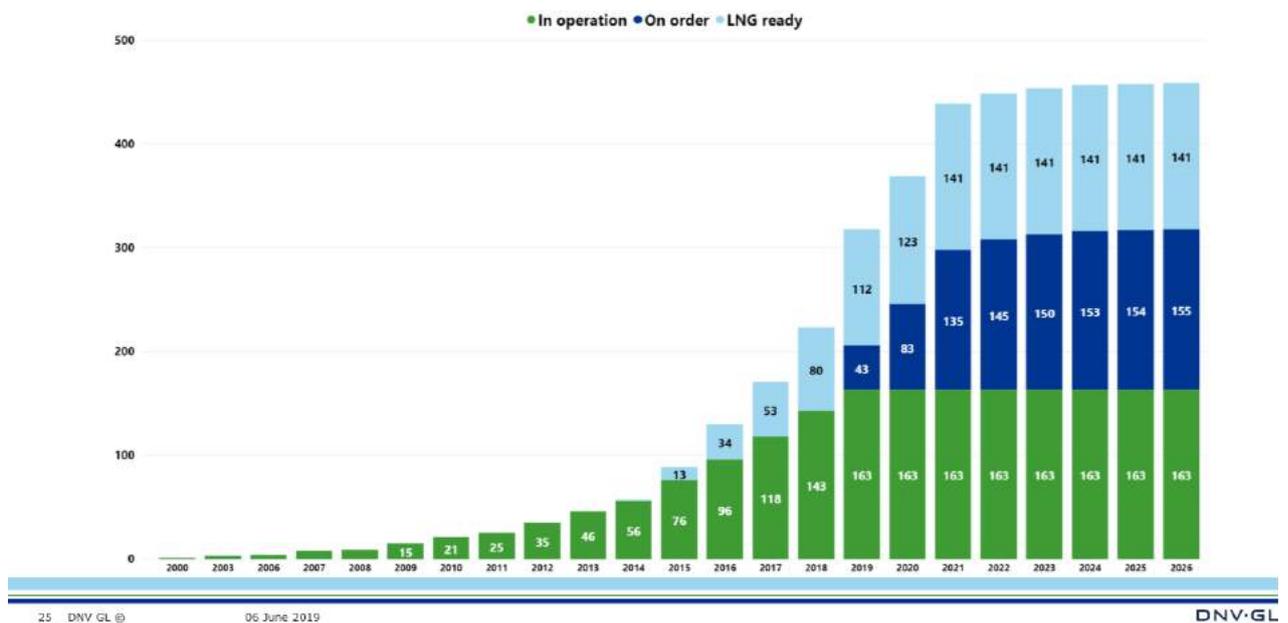
3.5. Marine Engine Application Segments

3.5.1. Ship Segments Overview

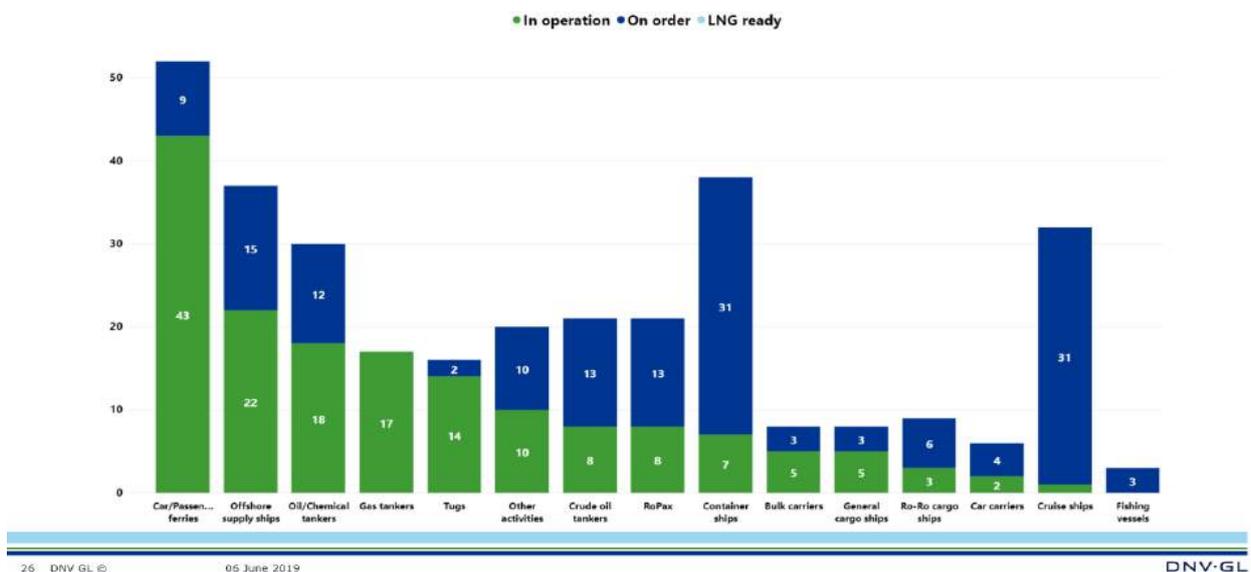
There are numerous marine segments that can utilise LPG as fuel. Already many examples of use of LNG as marine fuel exist, and LPG can follow the same paths. Some marine segments may be more attractive to the use of LPG as a fuel than others.

There are 318 confirmed LNG fuelled ships, and 141 additional LNG ready ships (2019). The number of LNG ready ships is expected to increase in 2020, reaching 123 vessels, with 163 operating and 83 being on order.

The number of LNG ships will in fact remain the same until 2026, but the LNG ready ships will increase to 141, with the orders gradually increasing every year, reaching 155 in 2026.



Car and passenger ferries will be using mostly LNG, as 43 are already in operation, followed by offshore supply ships with 22 and oil/chemical tankers with 18.



3.5.2. Commercial Vessels

Commercial vessels of all sizes can benefit of the use of LPG as engine fuel.



Two Stroke Diesel Engine

Large vessels have engines of all types, from two- or four-stroke diesel engines to turbines similar to those on airplanes or even just several diesel generators that power thrusters or pods. It all depends on what the ship is designed to do and how it will be operated.

The majority of large commercial ships, from freighters to oil tankers, use two-stroke, slow speed diesel engines connected directly to their propeller. The large two-stroke diesel engines are efficient for constant speed steaming and running on heavy fuel oil. Compared to other fuels, HFO is very cheap but also known for lots of heavy air pollutants including sulphur oxides and nitrogen oxides

3.5.2.1. Cargo ships

3.5.2.1.1. Large ocean-going ships-VLGCs

Getting a fully-laden cargo ship across an entire ocean requires enormous amounts of energy—usually derived from pollutant-rich diesel fuel.



Photo by BW LPG

An important benefit for using LPG in VLGC's is the elimination of the time taken for bunkering, since the engine would be burning the cargo. In case of LNG, a compressor/chiller is used to liquidise and feedback cargo vapour into the main cargo area, which would be unnecessary for LPG.

Currently, four LPG VLGC, the BW Gemini, Leo, Orion and Libra has been retrofitted to run on LPG. However, many companies have ordered LPG engines.

Case 1: World's First "LPG as Fuel" Order-Two EXMAR VLGCs will be LPG fuelled

Exmar has chosen LPG-burning, dual-fuel engines to propel a pair of VLGCs. The Belgian ship operator's VLGCs will be the world's first LPG-fuelled vessels. The ship and propulsion system design has been developed in tandem with Lloyd's Register, as the vessels' class society, and MAN Diesel & Turbo, the engine manufacturer.



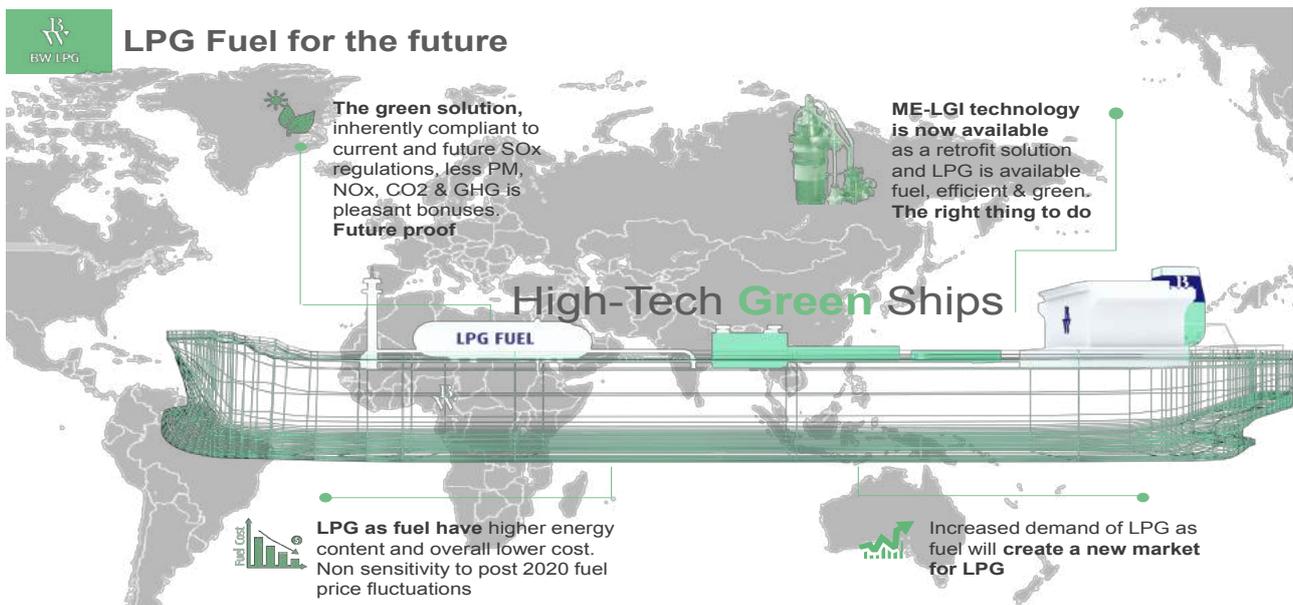
The technology group Wärtsilä will provide an integrated cargo handling and fuel gas system for two new gas carrier vessels for Exmar, the Belgium-based fleet owner. The ships, which will transport LPG, are being built at HHIC-Philippines (Hanjin Heavy

Industries & Construction Philippines) in Subic Bay. The design of these ships focuses on high efficiency and a more sustainable operational profile. In achieving this, these 79,500m³ VLGCs will be the first new build vessels capable of running on LPG. This valuable order was booked in July, 2018. On delivery in 2022 the newbuilding pair will go on long-term charter to Equinor.

These are ‘game-changing’ gas carriers and the aim has been to achieve the best possible operational and economic performance, while at the same time, ensuring the lowest possible environmental footprint.

Case 2: World’s First retrofitting of LPG-propelled dual-fuel engines-BW LPG to Retrofit 15 Ships

BW LPG has signed contracts including future options for the delivery and retrofitting of fifteen LPG-propelled dual-fuel



engines in its fleet, in a world’s first initiative. BW LPG first retrofitting, *BW Gemini*, the world’s first VLGC to be retrofitted to LPG dual-fuel propulsion technology, has successfully completed her historic crossing of the Pacific Ocean on LPG fuelled propulsion, and completed her loading at Enterprise Terminal in Houston.

The Very Large Gas Carriers (LPG) take lead

- lowering all emission types significantly

Vessel FACTS:
BW Gemini, 84,000 cbm VLGC, Owner BW LPG
Main Engine 6G60ME-C9.2 - 12,400 kW,

- built in 2015 to be fueled with HFO
- converted in 2020 to be fueled with LPG
- first LPG fueled vessel in the world
- 14 sister vessels will also be converted to LPG

Compared to OIL - LPG provide significant emission reductions:

- SOx by 99%
- CO2 by 15%
- NOx by 10%
- PM by 90%

MAN Energy Solutions MAN PrimeServ Webinar: Dual-fuel LPG conversions Nov 2020 2

BW Gemini is carrying a record load of 49,000 metric tons of LPG on a single keel. As the vessel refuelled while loading and no additional bunkering was needed, she has proceeded on her voyage. This turnaround translates to an increase

Cold Conversion



MAN Energy Solutions MAN PrimeServ

LPG as a marine fuel: lessons learned 08.03.2021 9

in the vessel's commercial availability for customers. BW LPG has committed to retrofitting 15 vessels at a combined cost of approximately \$130 million.

According to BW LPG, building new ships can provide the benefits of operating with LPG but comes at a heavy cost. Counting total emissions, a new ship represents about 70,000 tons of carbon dioxide in the materials and building process, compared to 2,000 tons of carbon dioxide for retrofitting, the sustainability outcome is much better from retrofitting than from building new vessels.

Output efficiencies will improve by ~11% with LPG vs compliant fuels. This means that they capture significant improvements in total voyage fuel economics. Other efficiencies gained with LPG include easy storage, faster refuelling and wide availability of bunkering ships and facilities. All these ensure that LPG is a long-term sustainable marine fuel.

Quotes

"Increasing BW LPG's total investment to fifteen dual-fuel propulsion engines is part of our corporate commitment to sustainable development. Through investments in pioneering propulsion technology, BW LPG modernizes its existing fleet and reduces our overall environmental impact."

Pontus Berg, Executive Vice President, Technical and Operations at BW LPG

"Retrofitting 15 of our vessels with pioneering LPG propulsion technology is a significant upfront commitment, but the returns are positive in both financial and environmental terms. It is the result of our company's focus to invest resources and expertise to pioneer technology that can be used to push our industry towards decarbonisation without the need for dedicated newbuilding orders."

Serge Schwalenstocker, Project Manager, BW LPG

BW LPG move the maritime industry a step towards a cleaner future.

Case 3: DORIAN LPG entered into a MOU to study to Retrofit ten Ships

Gas carrier owner and operator Dorian LPG has entered into a memorandum of understanding with Hyundai Global Service Co. to undertake research and preliminary engineering studies to upgrade the main engines of up to ten VLGCs to dual fuel technology, utilising LPG as fuel.

Dorian and Hyundai Global Services (HGS) are examining LPG as a marine fuel - in particular conversions to MAN Diesel & Turbo's forthcoming ME-LGIP dual-fuel engines - in anticipation of the IMO's global fuel sulphur cap, in force from 2020. The project follows a preliminary investigation into LPG as fuel conducted by Dorian and the American Bureau of Shipping.

DORIAN LPG had already added enhancements to its vessel design in recent new builds to allow for the option of using LPG. It noted that LPG has an advantage over other potential fuels given its abundant availability from the shale exploration boom and an existing global distribution network, with onshore and floating storage infrastructure.



LPG as Fuel: Techno-economic Study Life Cycle Cost Analysis from ABS is mentioned in Appendix 2.

Case 4: Astomos Energy

Astomos Energy, Japan's top LPG supplier, works towards promoting LPG as marine fuel. Kawasaki Heavy Industries (KHI) has recently developed a design of 80,000 cbm VLGC using LPG as fuel.

The newly developed VLGCs are equipped with ME-LGIP, a dual-fuel (DF) diesel engine that uses LPG and heavy oil as fuel as a main engine. LPG is used as a fuel to reduce sulphur oxides (SOx) that it can meet various environmental regulations.



ME-LGI, which is installed as a main engine in the newly developed VLGC, was unveiled at Gastech 2017. It is an engine that uses low flash point fuels such as LPG and methanol. Kawasaki is working on development of LPG-fuelled systems which include main engine, fuel supplying system and so on.

Meanwhile, Japan's Astomos, which operates the world's largest VLGC fleet, is now actively reviewing the application of the LPG fuel to the entire 22 VLGC fleet and is touting LPG as an alternative to CST380 bunkers. It plans to respond to international environmental regulations with DF diesel engine that uses LPG as fuel.

By 2020, Astomos Energy is considering LPG-fuelled VLGC, before promoting LPG as marine fuel for other vessel types, such as car carriers, container ships and bulk carriers. The company has already commenced collaborations with compatriot shipbuilders, ship owners and ship operators.

With regards to Astomos Energy's current fleet, the main engine of the vessels, ME-LGI, is manufactured by MAN Diesel & Turbo, and can be dually fuelled by LPG and HSFO.

In pushing for LPG as ship fuel, Astomos Energy considers that the infrastructure and availability are not issues because a global supply chain is already in place. It is also easier to handle LPG as its main components, propane and butane, are to be stored at -42° and -0.5° , respectively. Comparatively, the burning of LNG is more expensive due to the maintenance costs, as the gas has to be stored at -162° in cryogenic tanks. While there is already an established market for LPG trading, a spot market for LNG trading is far from stable. Currently, LNG purchases are very much dominated by long-term supply contracts, despite calls for more flexibility in the wake of weak prices. While LNG bunkering infrastructure will take time to develop, LPG supply networks are already in place, as Astomos Energy has supply networks in Singapore, the US Gulf, the Gulf and Europe.

Annually, the company imports over four million tonnes of LPG. As LPG production in the US Gulf is expected to grow with shale exploitation, the international LPG market will flourish, even as prices have become depressed.

Projects under development:

LPG case study

In connection with the Gastech 2017 conference and exhibition in Tokyo, project partners Consolidated Marine Management (CMM), Hyundai Heavy Industries (HHI), Wärtsilä Oil & Gas, and DNV GL presented the results of a joint industry project (JIP) to develop a new LPG fuelled carrier design – LPGreen. Launched at the Posidonia trade fair in 2016, the JIP sought to develop a more energy efficient, environmentally friendly, and safer vessel for the



transportation. The new concept design achieves state of the art performance on several fronts, according to the partners. Compared to the reference vessel, built to a standard design in 2016, there is an overall improvement of 6–9% in energy efficiency, depending on machinery configuration and fuel used. A redesign of the tank allows for a filling limit of 99% – a 1%

increase in overall carrying capacity. Loading duration has been decreased by 30%, while the newly designed cargo handling system concept results in a 5% reduction in energy demand.

LPGreen has also demonstrated the technical feasibility of a LPG-fuelled propulsion concept, which, depending on fuel prices and the development of a commercial and chartering framework, could result in a cut of up to 30% in fuel expenses.

KAWASAKI Newly Developed VLGC with ME-LGI

Profile

Features of the Design

- LPG as Fuel**
Kawasaki next stage VLGC is going to be sailed by 'LPG' as clean marine fuel. The propulsion system including LPG fuel supply system is developed by KHI.
- Excellent Propulsive Performance**
Propulsive performance is improved using RBS-F, SDS-F and SEA-Arrow (Sharp Entrance Angle bow as an Arrow)

CO2

SOx

LPG Fuel Supply system

Particulars

Loa	about 230 m	Main engine	1 x ME-LGI
-----	-------------	-------------	------------

Flow Diagram

Abbrivation

- Vent: Vent Riser
- P: Pump
- Knock Out: Knock out drum
- FVT: Fuel Valve Train
- SFSS: Secondary Fuel Supply System
- Amb-T / AT: Ambient Temperature
- HP / LP: High Pressure / Low Pressure

Color Code

- Low Pressure / Low Temperature LPG
- High Pressure / Ambient Temperature LPG
- LPG (HP / AT) and Lubrication Oil Mix.
- Ventilation (Air)

© 2017 MITSUBISHI HEAVY INDUSTRIES SHIPBUILDING CO., LTD. All Rights Reserved. Patent Pending



© 2017 MITSUBISHI HEAVY INDUSTRIES SHIPBUILDING CO., LTD. All Rights Reserved. 1

To realise these gains, the development partners used advanced computer analysis tools. Hull form optimisation both in calm water and waves was conducted using HHI's and DNV GL's CFD hydrodynamic optimization codes. The overall

concept system evaluation and optimization was conducted using DNV GL's COSSMOS modelling framework, which allowed for an integrated analytical approach to the evaluation of all machinery technology options and design improvements considered.

In order to increase the competitiveness of modern LPG carriers, novel ship designs need to simultaneously account for the market and trade route characteristics; excellent safety and ease of operation; cargo and fuel flexibility; and, overall energy efficiency combined with economic viability.

Therefore, a holistic approach to the design of modern LPG carriers is required, taking advantage of market insight, technology innovation, advanced computer tools and industry-wide collaboration with strong partnerships.

3.5.2.1.2. 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.



medium tanker Photo by Rolls-Royce



large tanker Photo by Rolls-Royce

LNG Powered Tankers

Currently, one tanker fuelled with LNG as a fuel is in operation 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.

LNG carriers have long been using LNG as a fuel by simply using their own cargo's "boil-off" gas but Dutch shipping company Anthony Veder is now having a pair of 4700-cubic-meter capacity Liquefied Ethylene Gas (LEG)/Liquefied Petroleum Gas (LPG) tankers built in China that will use LNG as a fuel but will not transport it as a cargo. To be completed by China's Avic-Dingheng Shipbuilding Co. Ltd for operation in the North Sea when delivered, the twin 99.95-meter by 17.20-meter vessels will make use of a propulsion package being furnished by Wärtsilä in which the main and auxiliary engines will be capable of operating on both LNG and marine diesel. The dual-fuel technology will allow the ships to sail without restriction in Sulphur Emission Control Areas (SECAs) and Nitrogen Emission Control Areas (NECAs).

3.5.2.1.3. 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 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 financial environment with slowing growth in this segment.

There are no large size bulk carriers that are being powered by LNG, but there have been some concept designs that have been developed.

Photo by Rolls-Royce

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.



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.

There are a great deal of opportunities for LPG in these vessel types.

3.5.2.1.4. Containerships

Containerships are one of the prime sources of pollution at sea. Since it has become very important in today's times to preserve and safeguard the marine eco-system, all major shipping companies are looking at designing ships that will cause very few polluting gases in the marine atmosphere. 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. 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.



Photo by Rolls-Royce

LNG fuelled containerships

- ▶ Owned by TOTE, in partnership with General Dynamics NASSCO, Isla Bella proudly flaunts the title of world's first LNG-powered containership. She is also the first of two Marlin class containerships and the largest LNG-powered dry cargo ship.
- ▶ The Jones Act-qualified ship is equipped with Daewoo Shipbuilding & Marine Engineering (DSME)'s patented LNG fuel-gas system and is also the world's first ship to be powered by a MAN ME-GI dual-fuel, slow-speed engine. This engine dramatically decreases NOx emissions by 98 percent, SOx by 97%, and carbon dioxide by 72%, making the ship the greenest vessel of its size. Not only does she feature a ballast water treatment system, but is also capable of burning diesel when needed, thereby further reducing the air-polluting emissions.
- ▶ 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.

LNG Powered ConRo Ships

Construction for the world's first LNG-powered ConRo Ships began in October 2014. The ships' design is provided by Wärtsilä Ship Design in conjunction with Crowley subsidiary Jensen Maritime. The main propulsion and auxiliary engines will be fuelled by environmentally-friendly LNG.

RORO ships

The world's largest LNG Powered RoRo Ferry has been ordered by Australian shipowner, SeaRoad and is under construction at Flensburger-Schiffbau-Gesellschaft (FSG) yard in Germany. At 181m, it will be the largest RoRo ferry with LNG propulsion and the first vessel of this type built by FSG.



3.5.3. Fishing Boat/Ships

LPG is a very attractive fuel in the fishing sector. Its undeniable environmental benefits make it an ideal fuel for use in environmentally protected areas, lakes, rivers but also largely in fishing fleets where water contamination from the marine fuel can have severe adverse effects.



The use of LPG as an engine fuel is particularly popular in boats operating in salmon fishing farms. Besides its environmental benefits, in many countries the use of LPG in the marine segment provides significant cost saving

opportunities for fleets and other boat operators. The US-based company, LEHR is a ground breaker in this sector, providing education and support to many countries globally that utilise LEHR LPG outboards & inboards engines solutions for port vessels, small passenger ferry, fishing fleets etc,. One type of lower cost engine used is the “long-tail”, a horizontal shaft utility engine mounted on a pivot on the transom with a long surface piercing propeller shaft. This type of utility engine is most popular in certain countries in Asia and now running on LPG it lowers the cost and improves the reliability for commercial fishermen.

Small fishing boats running on LPG

LPG 6.5HP Long-tail Engine

- ▶ Air-cooled four-stroke, single cylinder
- ▶ Bore*Stroke: 70*54mm
- ▶ Displacement: 212cc
- ▶ Max power: 4.7kW/3600rpm
- ▶ Max Torque: 13.0N.m/2500rpm
- ▶ Oil Capacity: .6L
- ▶ Ignition System: TCI



LPG 13HP Long-tail Engine

- ▶ Air-cooled four-stroke, single cylinder
- ▶ Bore*Stroke: 88*64mm
- ▶ Displacement: 389cc
- ▶ Max power: 9.7kW/3600rpm
- ▶ Max Torque: 26.4N.m/2500rpm
- ▶ Oil Capacity: 1.0L
- ▶ Ignition System: TCI
- ▶ Starting System: Recoil start



3.5.4. Passenger Vessels

The passenger vessel segment includes cruise vessels and ferries. Overall, the segment is small in the number of ships compared to the world's total shipbuilding demand, but the cruise segment offers ships of very high value and is almost completely dominated by European builders, while Europe also has a strong position with regard to ferries.



The market for cruise ships is strongly driven by tourism market trends. The passenger vessel segment is the most important part of the total European order book in terms of value. In terms of

turnover value, almost half (47%) of all vessels built in Europe are passenger and cruise vessels.

LNG powered passenger vessels

Although Norway has been a significant innovator of LNG propulsion the trend has been expanding internationally, with Italy's Lauro Shipping recently entering into an agreement that will see a series of gas-powered passenger/auto ferries developed for Mediterranean use based on Rolls-Royce's "Enviroship" programme. This will be the first use of the Enviroship concept in a passenger vessel and the design will include LNG-burning Bergen engines as well as wave piercing bows and combination Promas propeller/rudder systems, the latter to enhance both fuel efficiency and manoeuvrability.

In Australia, Incat Tasmania Pty Ltd has already completed the world's first LNG-burning high-speed passenger/auto ferry for operation by South America's Buquebus on the Buenos Aires - Montevideo run. The 50-knot vessel, with a capacity of 1,000 passengers and 140 vehicles, is the first high speed commercial craft to be powered by gas turbines using LNG as the primary fuel, while marine distillate is retained for standby and ancillary use.

In North America, Canada's Société des Traversiers du Québec (STQ) has ordered an 800-passenger/180-car LNG-powered ferry from Italy's Finantieri. Designed to operate on the St. Lawrence River, it will be North America's first ferry to be powered by LNG, although Washington State Ferries, BC Ferries and New York's Staten Island Ferries have all announced plans to begin using the fuel through retrofit programme.

3.5.4.1. Cruise ships

The cruise industry is expected to continue to grow due to the ageing of the population in the US and EU as well as cruises becoming more affordable.

In regards to the greening potential, most of the recently built cruise ships comply with the strictest regulatory regimes in existence as operators want their ships to be able to operate across the world, including attractive but vulnerable

pristine tourist destinations (the Baltics, Norway, Alaska). On the other hand, however a large number of older ships are still operational. **As these may not comply with the strictest environmental rules, retrofit opportunities might arise from green regulatory drivers.**



Carnival Corporation has ordered **four LNG-powered cruise ships**, two of which would join

the AIDA Cruises fleet. The construction will be carried out at Meyer Werft and Fincantieri S.p.A shipyards. The four new ships will also feature a revolutionary “green cruising” design. The ships will be the first in the cruise industry to be powered at sea by Liquefied Natural Gas (LNG) the world’s cleanest burning fossil fuel, representing a major environmental breakthrough.

Based on Carnival Corporation’s innovative new ship design, each of the four next-generation ships will have a total capacity of 6,600 guests, feature more than 5,000 lower berths, exceed 180,000 gross tons and incorporate an extensive number of guest-friendly features. The ships will be the first in the cruise industry to use **LNG in dual-powered hybrid engines** to power the ship both in port and on the open sea. LNG will be stored onboard and used to generate 100 percent power at sea, producing another industry-first innovation for Carnival Corporation and its brands. The expected delivery of these four cruise ships is between 2021-2022.

3.5.4.2. Ferries

Ferries within the harbour area are currently propelled with low-emission diesel engines. Due to short round-trips they can be re-fuelled frequently. For ferries that do not carry any cargo below deck there should be adequate enough space for gas fuel tanks to allow for bunker capacity for several days.



Ferries and RoPax vessels that operate in international service are all fuelled with conventional diesel engines burning low sulphur fuel. There is a strong potentiality that this fleet could be converted to LPG operation in later stages.

Most ferries services operate within one country. The leading ferry operating countries (by numbers of passengers served within their borders) are Greece, Italy, Denmark and Norway. Most ferries can be found in the Mediterranean Sea, the North Sea and the Baltic Sea.

The average age of the current ferry fleet in Europe is quite high (32% older than 30 years), indicating a replacement need. Furthermore, those ships operating in ECA areas (including all ferries operating the North Sea and the Baltic Sea) will have to meet certain emission standards which should create a demand for either retrofitting, or – for the older ships – earlier replacement.

A barrier to ship replacement however, is the funding capability of owners/operators, especially in ferry segments where returns are low or where government owned companies have to meet public service level agreements on commercially non-attractive routes. In other areas however, newbuilding replacements are seen on – apparently – commercially attractive routes. With regard to operating greener ships, a number of ferry operators (government supported or not) are choosing for ‘green’, e.g. ferries in Norwegian fjords, or the TESO ferry to Texel in the Netherlands.

The ferry market is a highly-differentiated market which encompasses large ferry operators that operate ferries that resemble small cruise vessels (e.g. Color Lines serving Norway/Sweden) and small ferry services that are active on specific routes in e.g. the Mediterranean. This makes it hard to draw general conclusions. Especially where ferries are operated by the larger sized ferry operator groups such as Stena, DFDS or Grimaldi, innovation processes appear to take place in close cooperation between yards and owners/operators. Smaller regionally operating ferry companies, often based on public service agreements, have a much lower bargaining power and are more strongly inclined to use standard ship types.

Still, innovation initiatives are found in this market, such as the STX France contract for 110 passengers ‘zero emissions’ ferry to serve the Lorient harbour crossing or hybrid ferries in Argyll County in Scotland. These innovations are often influenced by public bodies that support these investments as part of a wider greening strategy.

LNG powered Ferries

- ▶ 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 vessels, 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 Renditions of Société des traversiers Québec LNG ferries.
- ▶ 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.

LNG fuelled PORAX

World's First High Speed LNG Fuelled RoPax Ferry is being built for Swedish operator Rederi AB Gotland will be fuelled

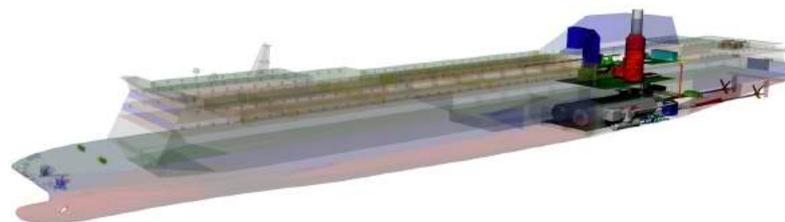


by LNG and will feature Wärtsilä's integrated solutions. The ship will carry approximately 1650 passengers, will have 1750 trailer lane metres and can accommodate a corresponding number of passenger cars, campers and buses. It has been designed to meet the DNV-GL classification society's high comfort ratings for climate, noise and vibration. Wärtsilä's scope of responsibility includes four Wärtsilä 50DF dual-fuel engines, two gearboxes, two controllable pitch propellers (CPPs) with remote control system, two Energopac rudders, two tunnel thrusters, four Wärtsilä 20DF dual-fuel auxiliary generating sets, two Wärtsilä LNGPac fuel gas handling systems, gas valve units, a compact silencer system (CSS), an IMO approved Wärtsilä

Aquarius UV ballast water management system, an Oily Water Separator together with a Bilge Water Guard to monitor and prevent oily water being discharged to the sea, project management services, integration engineering services, commissioning services and on-site supervision during installation.

LPG Case study: LPG Ferry Korea

GE's Marine Solutions reported on 23th May 2017 that the world's first LPG-fuelled ferry design to use GE's Combined



Gas Turbine Electric and Steam (COGES) system has successfully completed Hazard Identification (HAZID) meetings. The consortium of Youngsung Global, DINTEC, Korea LPG Industry Association, GE's Marine Solutions and Far East Ship Design & Engineering Co. (FESDEC) signed a multilateral memorandum of understanding

in November 2016 to cooperate on this unique ferry design concept.

The major players in the COGES LPG ferry concept are as below:

- ▶ Youngsung Global: Ferry owner
- ▶ DINTEC: Ferry operator
- ▶ GE's Marine Solutions: COGES propulsion system provider

- ▶ Answer: LPG fuel tank and gas supply system design
- ▶ FESDEC: LPG COGES ferry naval architect
- ▶ Korea LPG Industry Association: connects LPG providers with industries
- ▶ E1: LPG provider
- ▶ SK Gas: LPG provider

The increased use and future availability of LPG worldwide could make this exciting ferry project feasible. The ship is designed to ensure both economic benefits and environmental performances, adopting LPG as the main fuel for lower fuel costs and no emission of sulphur oxides (SOx). GE's compact and lightweight COGES system will provide for all ship power, including propulsion. An added benefit: the COGES system consumes almost no lube oil and meets current and future regulations for SOx, nitrogen oxides (NOx), carbon dioxide (CO₂) and particulate matter. Specifically, GE marine gas turbines meet International Maritime Organization Tier III and United States Environmental Protection Agency Tier 4 standards now without exhaust after treatment and no methane slip.

GE marine gas turbines are fuel flexible and can operate on a variety of fuels, including LPG, marine gas oil, biodiesel, bio-synthetic paraffinic kerosene blends and natural gas. The compact COGES arrangement — lighter and smaller than comparable diesel engines — allows for more revenue generating space on board ships and lower lifecycle costs. Maintenance of the COGES system requires only about 300 man-hours per year, and the entire turbine can be removed and replaced within 24 hours, reducing downtime for minimal interruption to ship operations. GE marine gas turbines range from 4.5 MW to 52 MW output for ship power and propulsion. These engines operate worldwide for diverse commercial marine customers on cruise ships, fast ferries, high speed luxury yachts, floating production storage and offloading ships and offshore platforms. In addition, over 1,400 GE marine gas turbines power nearly 500 military ships for 35 navies globally, logging some 14 million operating hours.

3.5.4.3. Yachts

US yacht builder Trinity Yachts is part of the Gulf Coast Group, so this LNG-fuelled yacht will be marketed under their name. The concept drawings transform the LNG concept from a functional workboat into a stylish explorer-style luxury yacht. It was conceived as an ocean-going expedition yacht with five decks above the main deck and a large, open aft deck. Space has been included on the open deck space for the stowage of a large tender, a helicopter pad and aft on the main working deck an A-frame launching system for a submersible. Its machinery will be based around a diesel-electric propulsion system with the electric power being generated by three generating sets supplied by Wärtsilä. Each of these is powered by a



Wärtsilä 6L 34DF diesel that develops 2610 kW and is capable of operating on dual fuel, diesel and LNG.

Wärtsilä 6L 34DF diesel that develops 2610 kW and is capable of operating on dual fuel, diesel and LNG.

In addition to being able to operate on LNG, the offshore versions building also meet the stringent criteria enabling her to qualify for the ABS Enviro+ Green Passport notation. When operating on only LNG, this vessel meets the new Tier IV sulphur and nitrogen oxide emissions regulations that will come into force for parts of the North American Emission Control Area and in many European waters.

3.5.5. Offshore Service Boats

Harvey Energy is the first vessel in North America to be powered primarily by liquefied natural gas (LNG). The pioneering offshore supply vessel (OSV) serves Shell in its deep-water offshore operations in the Gulf of Mexico. The vessel is powered by three Wärtsilä 6L34DF dual-fuel gensets that provide 7.5MW of power. Fuel is supplied to the engines through Wärtsilä's LNGPac gas storage and supply system.



3.5.5.1. Exploration and Production

3.5.5.1.1. Seismic Vessels

Seismic survey vessels have an unusually large engine room with abundant machinery for vessels of this size. The engine compartment has the auxiliary generator, harbour generator, compressors supplying air to the air guns or seismic source, generators for the compressors and engines for additional propulsion. These engines are usually of manufacturer Caterpillar or Wärtsilä. The combination of mechanical power, delivered by an LNG internal combustion engine, and electrical power, provided by range extenders, optimize the propulsion efficiency for ships with a flexible power demand.



3.5.5.1.2. Drill Ships

World's First LNG Fuelled Drillship will be built at South Korea's Daewoo Shipbuilding & Marine Engineering under joint development project (JDP) with ABS.



Photo by Rolls-Royce



Photo by Rolls-Royce



DSME has performed a concept design, comparison between two types of LNG storage tanks and analysis of the fuel gas supply system that will be installed on the drillship. ABS' scope of work calls for concept design review, basic engineering review and a risk assessment of the tank space and access area, fuel gas supply system, machinery space and access area and associated configurations.

3.5.5.1.3. Cable/Pipe Layers

A cable laying ship is created specifically to cater to the purpose of laying cable lines underwater. But at the same time since cable laying work does not take place round-the-clock and throughout the year, a cable laying ship is also additionally used as research ship to monitor various happenings in the oceanic and sea waters.

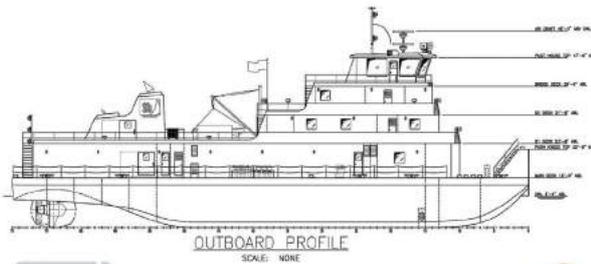


A distinction is made between cable layers operating inside and outside the wind parks. The latter group consist of larger vessels than the first. An important issue is the age of cable layers. Especially the smaller cable layers (up to 4,000 dwt) are quite old; many of these were built between 1975 and 1990 and are considered to be obsolete.

3.5.5.2. Towboats

There is an increased interest in gas fuelled Tugs and Towboats. Crowley Maritime Corporation, the Glosten Associates and Rolls-Royce have designed a LNG-fuelled Tug, intended for service in the port of Long Beach and in the Port of Los Angelis (Cavalier).

2011 GO CLEAN TOWBOAT



Wärtsilä with Ship Architects, Inc. are cooperating on a new concept LNG towboat design. These vessels are intended for inland waterways and river service.

Additionally, there is an extensive market for inland waterways both for cargo and tourist service. Historically LNG has been a forerunner in gas applications but it is likely that the price and availability of LPG will attract this market and that it will develop toward using LPG as fuel.



Towboat concept design. Image credit: Ship Architects. INC.

3.5.5.3. Supply + Service Boats

3.5.5.3.1. Platform Supply Vessel

Among Swedish shipping companies, Terntank has ordered four LNG ships, using EU funding. One of the vessels will be leased by the oil company Preem, which will enable the company to transport refinery products in a more sustainable way. The Swedish shipping company Sirius has also ordered an LNG ship that will be operated by Skangas.

Rem Eir, the world's largest LNG powered vessel has been built at Kleven Vreft shipyard and is owned by Remøy Shipping. It has been



Designed by Wärtsilä Ship Design. With a length of 92.5m, breadth 20m, and a deck

capacity of 1,080 m², Rem Eir is the world's largest environmentally friendly LNG powered PSV. The vessel has entered in a long-term chart with Equinor.

3.5.5.3.2.Anchor Handling Vessels



Anchor Handling Tug Supply (AHTS) vessels are mainly built to handle anchors for oil rigs, tow them to location, anchor them up and, in a few cases, serve as an Emergency Response and Rescue Vessel (ERRV). They are also used to transport supplies to and from offshore drilling rigs.

Global anchor handling tug supply (AHTS) vessels market expected to record a CAGR of more than 13% until 2022.

3.5.5.3.3.Safety Standby Vessels



This vessel is solely designed for standby operations. Its uncompromising build and fit-out ensures that every detail maximises its ability to facilitate these operations.

3.5.5.3.4.Installation vessels



The technology group Wärtsilä is to supply the engines and other propulsion machinery for a new offshore construction vessel being built at the Cosco shipyard in China. The ship owner is Belgian operator Dredging International (DEME). This will be the first vessel of its kind to be fuelled by liquefied natural gas (LNG) and in addition to the dual-fuel engines, Wärtsilä will also provide its LNGPac fuel storage and supply system and propulsion systems.

The vessel is expected to be delivered to the owners in 2018 and will undertake operations involving the installation of offshore windfarms in locations around the world. The vessel will be deployed by DEME's unit GeoSea for the construction of the largest offshore wind farms, to service the oil and gas industry and for decommissioning of offshore installations.

3.5.6. Recreational Crafts and Other Boats

The use of LPG in recreational vessels is not uncommon although gasoline and diesel engines are the most prevalent forms of propulsion. Some of these vessels would have inboard engines and others outboard engines. Other boats that fall into the recreational craft category include those involved in water sports including vessels such as speed or power boats, and water or jet skis. These vessels would be typically be fitted with gasoline four stroke or two stroke engines.



Image by X-Tech

These types of boats often operate in a seasonal pattern, with frequent use in summer months and possibly being dry docked during the winter. Refuelling of recreational vessels is typically done at the moorings, but as the boat might be used away from its normal base the refuelling could be undertaken at many different places. Recreational vessels that are used for sporting activities are more likely to be refuelled at one location, where they are normally based.

In that case, outboard petrol engines were converted to using LPG as fuel through the same technology that is used in the car industry.

3.5.6.1. Rib and Speed Boats

Rib boats, which are using outboard propane engines, are new in the market, nevertheless LPG-powered engines have gained a reputation for quality products that are also good for the environment. They offer a number of advantages over standard petrol-powered outboard engines while being priced about the same. LPG outboard engines have become a strong marine propulsion alternative in protected lakes and rivers, as well as in fish farms. While two-stroke gasoline engines are the predominant form of propulsion, without effective after-treatment systems the exhaust fumes are very polluting, especially due to the unburnt fuel from the exhaust, not to mention the spillages encountered when refuelling. These combine to have detrimental effects on the water and aquatic wildlife. Emission benefits stand as the primary driver behind the use of LPG-fuelled engines but there are also noteworthy cost benefits.

The restrictions on the use of gasoline internal combustion engines on many protected areas leave LPG fuelled outboard engines as the prime alternative for boat users.

LPG outboard engines offer the available power of internal combustion engines without the environmental detriment of petrol, whilst delivering extended engine life and reduced cost of operation.

Even in the more modern (multi-point) injection engines, the advantages are still significant, as there is usually no



exhaust after-treatment: Emissions will be less polluting due to heavier hydrocarbons (i. e. polycyclic aromatics) not present in the LPG exhaust gas. Particulate emissions that turn into methyl mercury in the water are virtually eliminated.

LPG is harmless for the ozone, it does not cause "greenhouse effect" and as a gas, it does not mix with the soil and water, therefore, does not pollute them. LPG is more reliable for occasional use equipment as is often the case with outboard

engines.

LPG outboards incorporate important features and advantages.

- ▶ Start easily when cold or warm without a choke.
- ▶ Eliminates problems of petrol with 10% ethanol (such as using preservative additives to prevent the normal degradation over time).
- ▶ No mixing of oil in petrol (in two-stroke outboards).
- ▶ No sparkplug fouling or engine flooding.
- ▶ Convenience of using inexpensive (refillable) propane bottles inserted directly into outboard housing (or larger external tank).
- ▶ No smoke, gasoline exhausts fumes, or gasoline smells.
- ▶ No need to filter fuel.
- ▶ Propane is readily available and generally cheaper than petrol.
- ▶ Fewer harmful emissions - better for the environment.

3.5.6.2. House Boats

LPG would often be the fuel of choice for cooking and space heating in house boats; supplying fuel to gas stoves and

catalytic wall mounted heaters. Another application might be LPG

refrigerators. The usage pattern for these boats range from

occasional use,

continuous use

where

houseboats are

the primary

dwelling, or

something in

between such as

hire vessels. The

amount of

energy required for these, non-engine, applications is relatively

small and a 15kg cylinder of LPG would typically last several days. These LPG cylinders would likely be stored externally,

at the aft of the vessel, where there is good ventilation rather like on a caravan.



3.5.7. Naval Vessels

Navy vessels must be able to accelerate to top speed in a short period of time therefore flexibility and a propulsion system's boost ability is very critical. These ships often have limited engine room space, but a high-power demand. The use of a hybrid system in such cases provides the necessary surplus power needed in the full-power mode.



Propeller noise emissions can be reduced dramatically when the propeller is operating in hydrodynamically good conditions with no cavitation at the propeller. As noise is a key factor in navy projects, a well-designed propulsion system will emit lower noise levels, preserving mission success with a quiet ship response.

3.5.7.1. Military

Four stroke diesel engines are designed to operate at multiple speeds and are usually connected to the propeller through a reduction gear. This piece of machinery takes the high-speed revolutions that four-stroke diesel engines are known for (can be upwards of several thousand revolutions per minute) and lowers it to a usable speed for the propeller (around 70-130 revolutions per minute). These engines are more common on



Naval and Coast Guard vessels that operate that operate over a range of speeds. Many Naval and Coast Guard vessels also utilize gas turbines, the same kind that power airplanes, as they can be more efficient and more powerful than diesel engines and give those vessels the ability to travel 30 or 40 knots, or even faster.

3.5.7.2. Rescue/Patrol

Offshore patrol ships are good examples of ships with applications for the hybrid system. Patrol ships can be operated



Photos by Rolls-Royce

at low speeds by the electric motor and at a high-power demand by the main engine and the PTI booster.

3.5.8. Others

3.5.8.1. Dredgers

Both in building and operating dredgers, Europe is leading. The top four dredging companies, DEME, Van Oord, Jan de Nul and Boskalis, are all located in Belgium and the Netherlands and together cover some 80% of the worldwide open tender market. IHC Merwede in the Netherlands is world market leader in the construction of sophisticated and highly specialised dredgers.



In this segment, clients are very knowledgeable of their ships, which they usually operate during the entire economic life of 30-35 years. New orders are often related to specific projects for which unique performance or other specific environmental and

technical requirements are to be met. The segment therefore delivers highly specialised and tailored products. On the other hand, modifications of vessels need to be possible based on standard functionalities, in order to allow fleet reallocation to different assignments.

In 2009, the Middle East, Europe and China were the largest dredging markets, representing 59% of global turnover. Especially the Middle East was a booming region with projects like ‘Palm Island’ and ‘The World’ in Dubai. This has led to high demand for new vessels, as well as for major investments in the renovation and upgrading of equipment.

Clients in this specific industry heavily influence the introduction of innovations. As many clients are public or semi-public authorities, some clients demand green services and thereby trigger green innovations. Other clients focus on cost efficiency. However, it is the ship owners that determine the kinds of innovation they are willing to implement. For the clients that place high value on environmental performance, ship owners include environmentally friendly technologies and innovations in their offer. For example, for the Port Authority of Melbourne it was very important to limit the oil spillage. Boskalis offered an oil catching technology which convinced the client. This type of ‘green’ innovation referred to soil turbidity and the protection of coral reefs rather than to emissions.

LNG powered dredger

Scheldt River is a new generation “Antigoon” class dredger, being built by Royal IHC (IHC) in the Netherlands on behalf



of the Belgium based DEME Group and will be powered by Wärtsilä Dual Fuel Engines. Operating on LNG allows DEME to set new standards in minimising harmful emissions. “Scheldt River” will easily comply with all local and international environmental regulations.

The scope of supply includes one 12-cylinder and one 9-cylinder Wärtsilä 34DF engines, two Wärtsilä controllable pitch propellers and two

transverse thrusters as well as the company’s patented LNGPac gas supply and storage system. Scheldt River will be the first ever dredger to operate on engines capable of utilising **either LNG or conventional marine fuels**.

3.5.8.2. Tugs- Work Boats

First LNG-Powered Tugs

The vessels, Borgøy and Bokn, are designed by the Norwegian tug owner Buksér og Berging AS and built by the Turkish yard Sanmar. These are the first tugs to be fuelled by the much more environmentally friendly LNG to eliminate sulphur emissions, bring particulate matter emissions down close to zero and reduce the discharge of CO₂ and NO_x by 26% and 80- 90% respectively.



Powering each of the new tugs is a pair of lean-burn gas engines from Rolls-Royce Bergen, with a combined output of 3410kW at 1,000 rev/min. The engines are direct coupled to Rolls-Royce azimuthing Z-drives mounted aft in ASD configuration.

Photo by Rolls-Royce

Niigata Power Systems Co., Ltd., (Niigata) built unit of the new dual fuel engine 6L28AHX-DF from Keihin Dock Co., Ltd., used as the main engine for the LNG-fuelled tugboat built by NYK Lines, which runs either on diesel fuel or LNG. The tugboat is the first ship fuelled by LNG in Japan other than the LNG carrier, and the order for the engine is the first gas engine for marine application in Japan.



3.5.8.3. Ice Breakers

In order to exploit opportunities related to the development of Arctic shipping routes, ice breakers and ice strengthened ships will be required. The overall global market potential is estimated at some 15-20 ice breakers until 2020. In addition, a demand for ice strengthened ships, both for freight shipping and offshore oil and gas applications, will be created powered by clean fuel engines.



3.6. Conversions and Retrofitting

Ideally, a vessel should be originally designed for the use of gaseous fuel. Retrofitting is also possible, however the



retrofitting of a vessel originally designed for traditional marine fuels, or even LNG, needs to take into account additional measures to cope with the event of a leak, especially in the engine compartment or engine room. The location of the LPG storage tanks and fuel lines on board would also have to be carefully positioned for the same reasons. It is a different matter for new builds originally designed for LPG, where all necessary precautions are taken in the design phase to

prevent any build-up of LPG in low areas and ensure any leaks escape safely overboard.

Example: Outboard marine engines LPG conversions

Italy-based Power Sea Saver is one company that has taken select marinised engines and developed kits that convert those engines to propane.

This marine engine LPG system is streamlined for out/inboard and outboard EFI MPI 4- strokes engines and provided with composite, translucent approved cylinders that are very light and rust free.

The conversion is in compliance to the EU Regulation 15609/2012 and utilizing exclusively ECE ONU R67/01 approved components. Minor modifications are required, without the need to alter the engine's mechanical or electrical features. The system does not interfere with the original diagnosis system and is capable of drastically decreasing emissions and all those harmful gases produced by gasoline combustion. The result is less carbon and residues, less maintenance, reduced clogging and sludge build-up, thus ensuring better spark plug performance LPG is much cleaner than unleaded gasoline. When it comes to fuel LPG is a real money saver savings up to 40% depending on its local price.



*Note: This type conversion engine starts on petrol then switch to LPG once warm up mode is completed.
Outboard Suzuki 140 bifuel LPG*

Its components are designed to resist the typical drawbacks of marine environment, such as high salt-content waters and galvanic currents. It is composed of specifically stream elements for outboard, in/outboard and inboard engines and with appropriate modifications (as soon as the regulation concerning fuelling at the piers are approved). As to fuelling, marine and car engines differ from one another in that the LPG flow in a boat engine occurs at a fairly significant and continuous rate. For example, mounted with a 140 HP outboard engine running at a speed of 22 knots (40 km/h) consumes about 0.3-0.5 litres of fuel per minute, whereas, a boat mounted with a 250 HP outboard engine consumes about 0.4-0.7 litres of fuel per minute. Therefore, a few adaptations are required to ensure continuous vaporisation in an engine with an open loop cooling system.

3.7. LPG vs LNG

LNG and LPG are alternative fuels currently available than can be used to reduce environmental footprint. A move from traditional fuels to these gaseous fuels, is always based on some key considerations as:

- ▶ Compliance with environmental regulations and primarily SOx compliance for large shipping.
- ▶ Availability of the fuel.
- ▶ Cost considerations, cost effectiveness, upfront costs and running costs comparatively.
- ▶ Technology available (known and proven technology), availability of engines for these fuels.

Other key criteria are the routes the vessel operates, the autonomy it needs, idle time, availability, infrastructure, price, etc. Rules and regulations in the ports of operation are also key parameters.

Despite high start-up investment, with LPG-fuelled vessels (as with LNG) cash flow is positive from the start

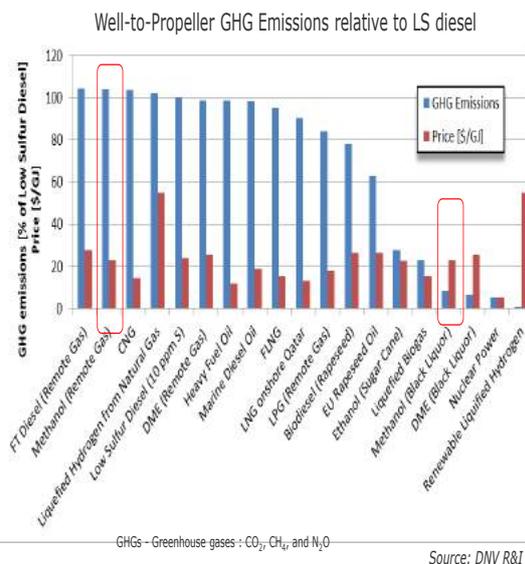
- ▶ LPG compared to LNG has the advantage of lower implementation and equipment costs and significantly larger available infrastructure of less-costly terminals, storage and supply points, which is particularly important for bunkering operations.
- ▶ LPG has also a significant potential in certain sectors including small tankers, container vessels and ro-ro ships that operate in coastal areas and on inland waterways where LPG supply infrastructure is always in proximity. LPG is a well-established fuel that enjoys a mature, global supply network.

Gas carriers of LNG will always have additional advantages by using LNG as a fuel, whereas the same will be also for LPG carriers that can easily use LPG as a fuel.

Alternative fuels - parameters				
Fuel type	LNG	Ethane	Methanol	LPG
Heat capacity	49200 kJ/kg	47500 kJ/kg	20000 kJ/kg	46000 kJ/kg
Specific Gravity	0.42	0.55	0.80	0.58
Volume factor (ref. MDO)	1.83	1.47	2.40	1.44
FGSS cost 15 MW	2.5 mill.USD	2.8 mill.USD	0.41 mill.USD	0.90 mill.USD
Availability	+	-	+	+++
Engine price	+20 %	+ 20%	+30%	+30%
Fuel Price (ref. MGO)	++	+++	+	++

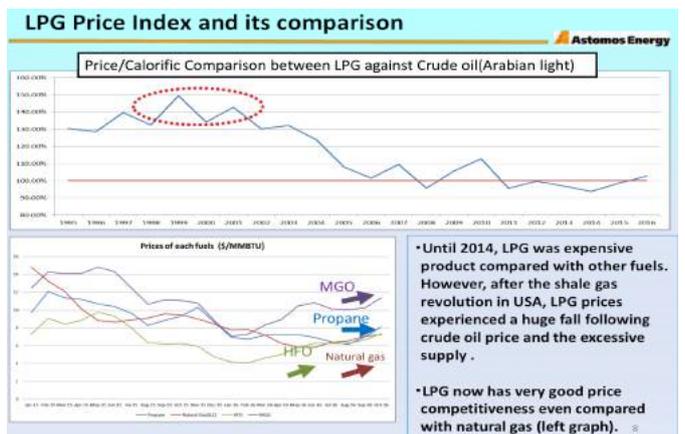
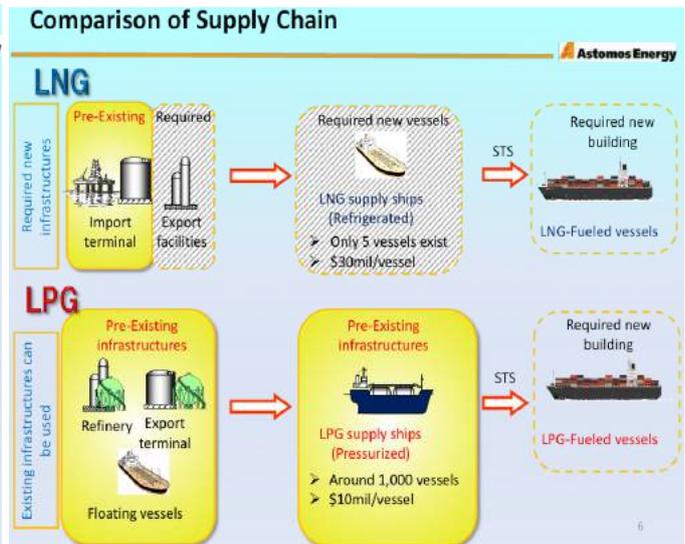
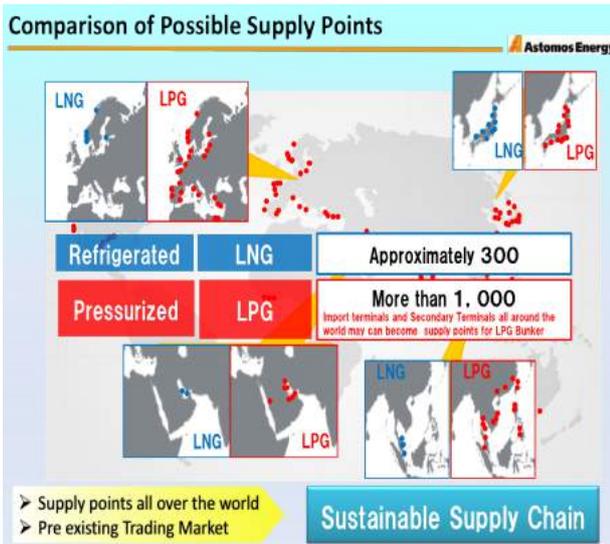
Ungraded
Source: MAN
DNV GL © 31 October 2016 DNV-GL

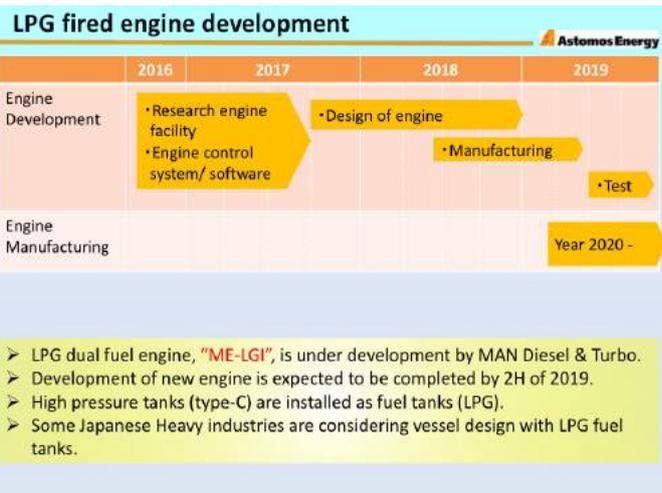
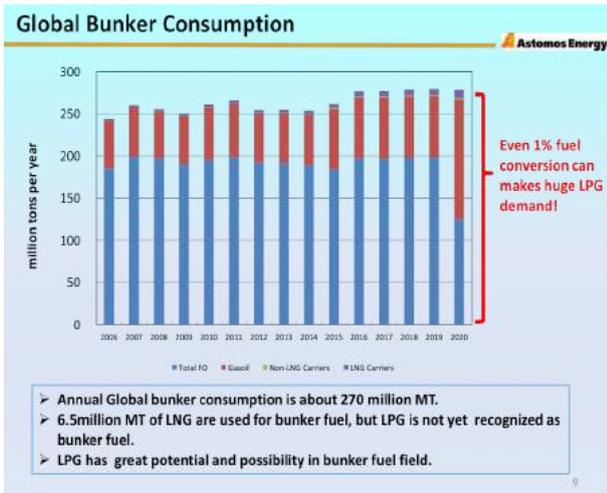
Sustainability and cost of alternative fuels



Properties		HFO	LNG	LPG	In comparison with HFO	
		(RMH380)	(Depend on production area)	(Almost equality)	LNG	LPG
Specific Gravity	kg/m3	app 991.0	app 420	app 580	To keep same energy supply Weigh: Nearly equivalent Volume: Around two (2) times, but to accommodate independent LNG tank in Ship, it will be requested three (3) times space	To keep same energy supply Weigh: Nearly equivalent Volume: Around one half (1.5) times, but to accommodate independent LPG tank in Ship, it will be requested two half (2.5) times space
Lower Calorific value	MJ/kg	app 40.4	app 50	app 46		
	MJ/m3	app 40.0	app 21	app 27		
Boiling point	°C	< 60	- 162	- 42	Independent tank (s) Heat Insulation BOG treatment unit	Independent pressurized normal temperature tank (s) Neither heat insulation nor BOG treatment unit are requested
Boil Off Gas	--	--	Generate	Suppressible by normal temperature pressurization		
Sulfur	%	3.5	0.0	0.0	No SOx emissions	No SOx emissions

© 2018 MITSUBISHI SHIPBUILDING CO, LTD. All Rights Reserved.





Characteristics of each fuel option

	Fuel Oil	LNG	LPG
Quality	Variable depending on refinery configuration	Variable HV depending on origin "Rich" or "Lean"	Global standardized quality
Transportation	Easy Low Cost	Operational Complexity Expensive	Relatively Easy Affordable
Infrastructure	Accessible intensive existing infrastructure	Limited availability mainly booked by utility companies	Intensive existing infrastructure
Storage	Easy containment system	Special containment system (cryogenic)	2 containment systems (pressurized/refrigerated)
Tradability	Commoditized non-discriminatory market	Limited market liquidity Contractual rigidity	Accessible open market Contractual flexibility



General Assumptions - CAPEX

SOX EGCS (Scrubbers)

TANKER - SUEZMAX			
CAPEX	M/E Only	M/E + A/E	M/E + A/E + A/B
Open Loop	\$1,380,000	\$1,580,000	\$1,910,000
Hybrid	\$1,650,000	\$1,900,000	\$2,458,000

BULK CARRIER - CAPEZISE			
CAPEX	M/E Only	M/E + A/E	M/E + A/E + A/B
Open Loop	\$1,490,000	\$1,540,000	\$1,850,000
Hybrid	\$1,550,000	\$1,730,000	\$2,090,000

GAS CARRIER			
CAPEX	M/E Only	M/E + A/E	M/E + A/E + A/B
Open Loop	\$1,280,000	\$1,400,000	\$1,630,000
Hybrid	\$1,600,000	\$1,780,000	\$1,900,000

- Installation costs:**
- 100 to 140% of CAPEX
- Design and Class costs:**
- \$125,000 Open Loop, \$150,000 Hybrid

LNG as Fuel

LNG CONVERSION - Machinery			
Item	Q/ty	Unit Cost	Total Cost
Total Cost	1	\$2,500,000	\$2,500,000

LNG CONVERSION - Storage			
Item	Q/ty	Unit Cost	Total Cost
Tank	2	\$1,500,000	\$3,000,000
Gas Handling	1	\$1,500,000	\$1,500,000
Install. Cost	2	\$625,000	\$1,250,000
Total Cost			\$5,750,000

LNG CONVERSION - Outfit			
Item	Q/ty	Unit Cost	Total Cost
GVU Rooms	5	\$100,000	\$500,000
Double Wall Pipe	3	\$100,000	\$300,000
Vent Riser & Mast	2	\$200,000	\$400,000
Bunker Sta. & Pipe	2	\$100,000	\$200,000
Ventilation	1	\$300,000	\$300,000
Total			\$1,700,000
Total CAPEX			\$9,950,000

LPG as Fuel

LPG CONVERSION - Machinery			
Item	Q/ty	Unit Cost	Total Cost
M/E Cost	1	\$1,000,000	\$1,000,000

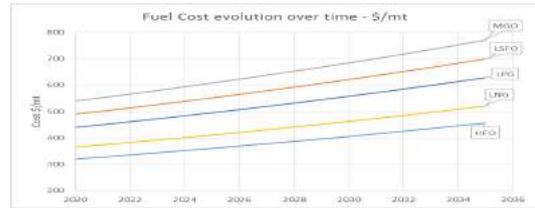
LPG CONVERSION - Storage			
Item	Q/ty	Unit Cost	Total Cost
Total Cost	1	\$1,000,000	\$4,000,000

LPG CONVERSION - Outfit			
Item	Q/ty	Unit Cost	Total Cost
Total Cost	1	\$1,000,000	\$1,000,000
Total CAPEX			\$6,000,000



General Assumptions - OPEX

- System Life expectancy of system 15 years
- Initial Fuel Cost 2020 (2.4% annual increase):
 - HFO: \$320/mt, LSFO: \$490/mt, MGO: \$540/mt.
 - Scrubber OPEX
- Additional 1% M/E Fuel consumption due to increased back pressure
- 1 to 1.3t/day extra consumption due to the additional electrical load
- Caustic Soda Cost: \$250 per ton and \$2,500 per bunkering
- Maintenance: 2% of CAPEX per year for open loop and 3% for Hybrid
- Service Engineer and Crew training: \$15,000 per year
- Cost of cargo lost due to system weight:
 - Tanker: 46U.S.\$/t approx. 650 U.S.\$/year
 - Bulk Carrier: 32U.S.\$/t approx. 450 U.S.\$/year
 - Gas Carrier: 135U.S.\$/t approx. 1,750 U.S.\$/year
- Extra 4.1 t of CO2 emitted per day (assuming a CO2 Tax 10 U.S.\$/tonne CO2)
 - Tanker: 9,700 U.S.\$/year
 - Bulk Carrier: 11,100 U.S.\$/year
 - Gas Carrier: 8,600 U.S.\$/year (based on 3.1t of CO2 emitted per day)



LNG as fuel: \$365/mt equivalent to 1 mt MGO

LNG Cost Calculation	
Commodity Cost	3.5\$/GJ
Liquefaction Service	4\$/GJ
Total	7.5\$/GJ
Cost per MGO equiv.	318.75\$
Convert to NCV	347.76\$

LPG as fuel: 440 \$/mt equivalent to 1 mt MGO

- M/E consumption 10% lower



LNG and LPG as Fuel Results

LNG Results for the Vessels:

- Discounted Payback Period:

LNG Conversion	TANKER - SUEZMAX DPP
M/E, A/E and A/B	4.7

- Life Cycle Cost Analysis indexes :

LNG Conversion	TANKER - SUEZMAX
ROI (% per year)	20.80
NS	\$18,307,474
SIR	3.3
AIRR	11.6

LPG Results for the Vessels:

- Discounted Payback Period:

LPG Conversion	GAS CARRIER - DPP
M/E	3.8

- Life Cycle Cost Analysis Indexes:

LPG Conversion	GAS CARRIER
ROI (% per year)	25.18
NS	\$19,090,955
SIR	5.3
AIRR	11.9

Study on Costs and Benefits of Alternative Fuels for an LR1 Product Tanker

Joint Study from a DNV GL and MAN Diesel & Turbo

Length, O.A.	225 m
Breadth, Mid.	32.26 m
Scantling draught	14.2 m
Design draught	12.2 m
Main engine	1 x MAN B&W 6G60ME-C9.5
NCR (90% SMCR)	10 390 kW at 88.8 rpm
Design speed at NCR	15 knots, incl. 15% sea margin
PTO	Fixed ratio, 778 kW
GenSet	3 x MAN 7L23/30H at 944 kW
SMCR	11,500 kW at 92 rpm

Table 1: Main particulars of the selected ship

The goal of this study was to analyse costs and benefits of various fuel options for a case with one particular ship and its operating pattern. The alternative fuels selected were LNG, LPG, methanol and a new ultra-low-sulphur fuel oil, a so-called hybrid fuel. Costs and benefits for a new build were determined by looking at its additional investment and operating costs compared to a standard fuel variant using HFO and MGO. An LR1 product tanker on a fixed route was selected to perform a financial analysis. For the various fuels, the machinery setup was the same, except for the fuel system. Product tanker is a market segment where DNV-GL expects an annual growth to 2020 in tonnage demand of 3 to 3.5%. The general arrangement of the selected ship is shown in table 1.

Operating pattern

The ship is assumed to operate on a route between Northern America and Northern Europe: Houston-Rotterdam-Ventspils-Houston. From the total distance of about 11,700 nautical miles, approximately 37% is inside a SECA.



Fig. 2: Selected route between Northern America and Europe

The typical speed for similar sized product tankers on similar trades was determined from AIS data to be about 12.5 knots, and this speed was then used as fixed transit speed of the ship. With 360 operating days, a year this corresponds to about eight roundtrips per year with 87% of the time spend in transit, 3% in approach and 10% in port. The selected route is shown in Fig. 2. Typical cargoes from Europe could be light diesel and returning from North America heavier distillates, e.g. marine gas oil.

Fuel variants

The main idea of the study was to investigate different fuel options for the selected product tanker on the selected route. The reference fuel case consists of HFO outside of SECA and MGO inside. In this study, the reduction in global sulphur cap has been assumed to be enforced from 2020, and hence LSFO with 0.5% S is the reference fuel outside of SECA from 2020.

Variant	Inside ECA	Outside ECA, 2018-2019	Outside ECA, 2020
Reference	MGO	HFO	LSFO 0.5%
LNG	LNG	LNG	LNG
LPG	LPG	LPG	LPG
Methanol	Methanol	Methanol	Methanol
LNG/HFO	LNG	HFO	LSFO 0.5%
LPG/HFO	LPG	HFO	LSFO 0.5%
Methanol/HFO	Methanol	HFO	LSFO 0.5%
ULSFO 0.1%	ULSFO 0.1%	ULSFO 0.1%	ULSFO 0.1%

Table 2: Fuel variants defined for this study

Table 2 shows the fuel variants considered in this study. For the alternative fuels considered (LNG, LPG, and methanol), one variant includes use of the alternative fuel for the entire round trip one-fuel variant, e.g. denoted "LNG"), while a second variant assumes use of the alternative fuel in the SECAs only and HFO/LSFO outside (mixed fuel variant, e.g. denoted "LNG/HFO").

Renewable diesel (also called hydrogenated vegetable oil) was also considered in the beginning of the study. It is a high-quality biofuel produced from vegetable oil and animal fat, but the current price of about 1000 €/tonne renders it uncompetitive in this study.

LNG and LPG can reduce the carbon footprint by up to 20%, depending on how the fuel is produced. Methanol offers future potential reductions by production from renewable sources, possibly at a lower cost premium than LNG and LPG.

The additional investment costs relative to the reference scenario for tanks, piping and engine modification were considered in the financial analyses, see Fig. 3. It has been assumed that tanks are placed on deck thereby not reducing the cargo capacity and, thus, earnings. Measures needed to reduce NOx emission to IMO Tier III levels were, for simplicity, assumed to be at a similar overall cost for all the fuel variants and, hence, neglected from the study. The investment year was set to be 2017 with operations between 2018 and 2030.

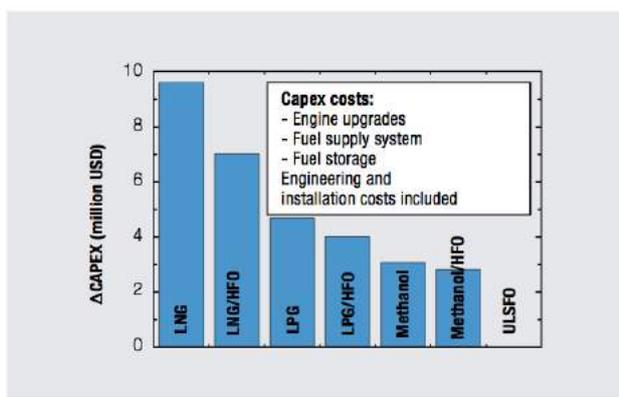


Fig. 3: Incremental investment costs for the alternative fuel variants

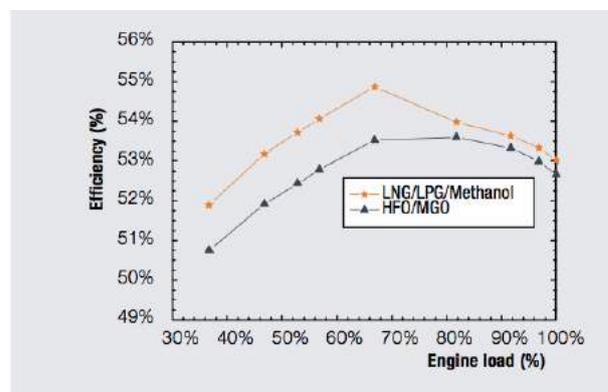


Fig. 4: Efficiencies of MAN B&W 6G60ME-C9.5 for the fuels at different engine loads

Machinery

An MAN B&W 6G60ME-C9.5 was selected as the main engine. This provides the ship with a design speed of 15 knots at 90% engine load, including a 15% sea margin. The calculated power for propulsion to reach 12.5 knots is 5.3 MW. Specific fuel oil consumptions for this engine for each fuel at various engine loads were used in the calculations, and the efficiency is shown in Fig. 4. The 6G60ME-C9.5 engine is available as a standard oil fuelled diesel engine, but also in dual fuel versions capable of burning LNG, methanol or LPG (the ME-GI and ME-LGI types, respectively).

The propulsion system is equipped with a fixed-ratio power take off (PTO). The capacity of the PTO is 778 kW offering a simple and cost-effective way to supply all the electric power from an alternative fuel when the ship is in transit. Apart from the reduced investment in equipping auxiliary engines for alternative fuel operation, the PTO also minimises the maintenance cost on the generation sets. In approach and port, auxiliary engines running on MGO are used, as illustrated in Fig. 5. For more information about different PTO configurations, see MDT paper No. 5510-003-02, shaft generators for low-speed main engines.

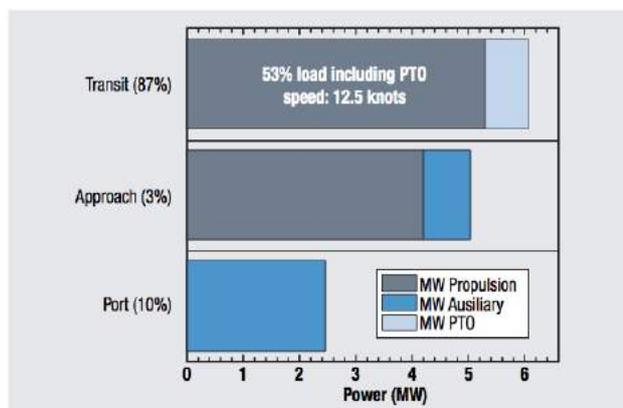


Fig. 5: Power generated and distributed between PTO, main engine and auxiliary engines for the trading pattern selected

the maintenance cost on the generation sets. In approach and port, auxiliary engines running on MGO are used, as illustrated in Fig. 5. For more information about different PTO configurations, see MDT paper No. 5510-003-02, shaft generators for low-speed main engines.

The main engine is for the three alternative fuel options equipped with a second fuel system enabling the engine to work as a dual fuel engine. This engine configuration offers full fuel flexibility with the same available power in both fuel oil and second fuel mode. Fuel oil mode (or MGO mode in SECAs) acts as fall-back mode in case of unintended

interruption of the second fuel mode. For this reason, the original fuel oil tank capacity is kept unchanged in this study.

The tank size for the alternative fuels was selected to give the vessel half-round-trip endurance with a 20% margin. This limits the investment costs, but increases the exposure to volatile fuel prices. For LPG and LNG, the tanks are placed on deck, and for methanol in the double-bottom of the ship. In all cases the cargo capacity of the case ship is left unchanged, and it has been assumed that there is no significant change in the draught of the vessel for any mass change of the ship related to use of the alternative fuels.

Fuel price scenarios

The fuel price scenario is important for the financial viability of the various fuel options. Historic fuel prices are shown in Fig. 6 for the last five years. Apart from the variations expected for each fuel type, the relative position of the fuel prices has changed over the period. MGO has become less expensive than methanol, and LNG has become equally expensive as LPG. In addition, the price difference between HFO and LNG has decreased recently.

Two price scenarios were developed:

1. High-price scenario based on mid- 2014 fuel prices at a time when Brent oil was at 100-110 \$/barrel.
2. Low-price scenario based on mid- 2015 fuel prices when Brent oil prices were about 50 \$/barrel.

For each scenario, an annual increase in fuel prices of 1% has been assumed, due to expected increase in oil and gas production costs.

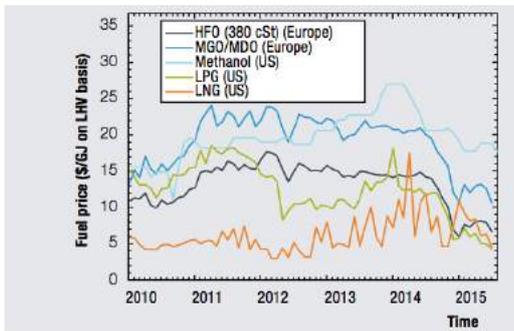


Fig. 6: Historic fuel prices on energy basis

The LNG distribution costs are estimated to 100 \$/t, or about 2 \$/mm btu, based on basis of the cost of operating an LNG bunkering barge. These costs are assumed to stay constant over time. Similarly, the distribution costs of LPG are considered to be half the distribution costs of LNG, i.e. 50 \$/t.

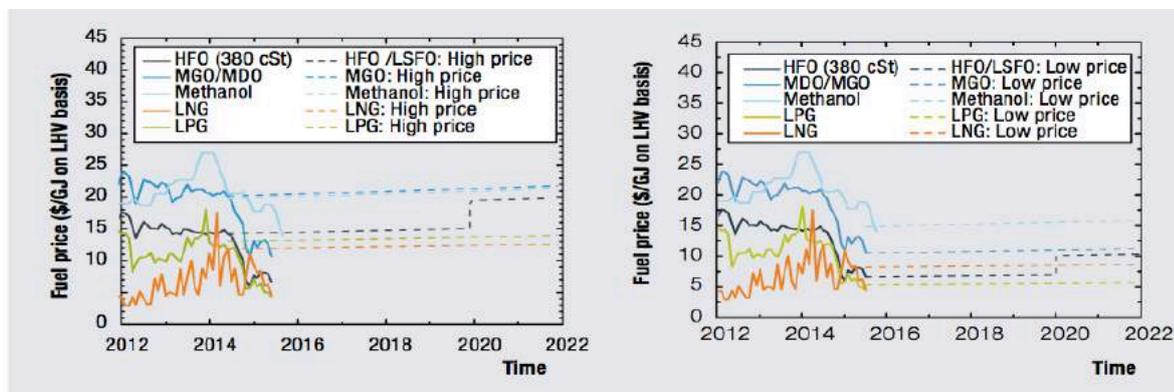


Fig. 7: Fuel price scenarios: high-price scenario (left) and low-price scenario (right)

The two price scenarios are illustrated in Fig. 7 based on the historic prices shown in Fig. 6. For the purpose of the analysis, we have differentiated between the prices in USA and Europe. For methanol and HFO, the prices are the same at the exchange rates. For LPG and LNG, the prices are cheaper in USA, whereas for MGO the prices have been

considered lower in Europe. It should be noted that the price of the reference fuel outside SECAs is changing in 2020, from HFO to LSFO.

Results

For each fuel variant, the investment cost difference and the annual cost differences have been determined, see Fig. 8. The diagrams show cost difference (either advantage or disadvantage) for the various fuels against the reference variant for both fuel price scenarios.

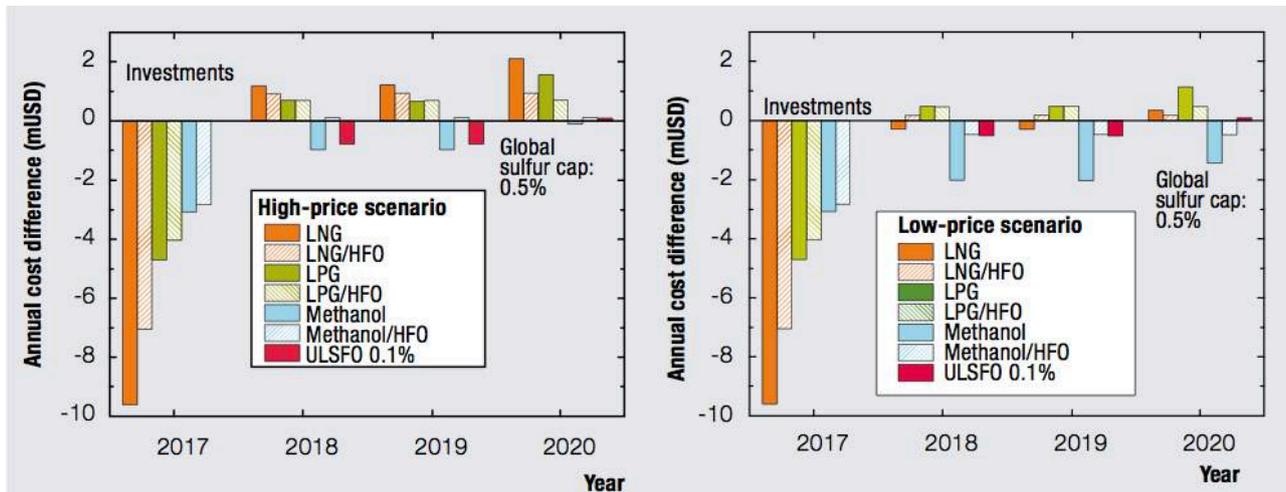


Fig. 8: Annual cost difference for the various fuel variants under the two price scenarios: high-price scenario (left) and low-price scenario (right)

In the high-price scenario, both in the one-fuel variants and mixed fuel variants, LNG and LPG deliver a cost advantage in operation when compared to the reference. However, these alternatives call for substantial investments. A large part of this, in particular for LNG, is related to investments for the tanks.

For the one-fuel variants, the cost advantage improves significantly after the global 0.5% sulphur cap enters into force. However, for the mixed-fuel variant, where the alternative fuel is only used in the SECA, the annual cost difference does not change by the global sulphur cap, because both the reference case and the project case change in the same way (from HFO to LSFO) outside SECA. However, since the fuel price is lower for LNG and LPG than for LSFO, the one-fuel variant becomes financially more attractive after the global sulphur cap.

LNG and LPG are both less attractive in the low-price scenarios. The cost difference for LPG stays positive for all operational years, whereas LNG is estimated to be negative before the global sulphur cap and positive after.

Methanol does not give a positive cost difference compared to the reference case for any of the price scenarios, and hence the investment needed for engine upgrade, gas supply system and tanks is not paid back.

Methanol becomes financially attractive if the methanol price drops, while the other fuel prices remain constant. If the methanol price drops to 18-20% below the MGO price, the high-price scenario will have a payback time similar to that of LNG and LPG. For the low-price scenario, the methanol price needs to drop even more. Such lower prices for methanol are more likely to become a reality if a lower grade fuel methanol is introduced on the fuel market.

Another option is to use ULSFO (hybrid fuel) for the entire round trip. The benefit of this is to avoid the compatibility issues related to fuel changes between hybrids fuel and HFO when entering/ leaving SECAs. Nevertheless, even after the global sulphur cap, the annual fuel costs for this scenario are at the same level and, therefore, not better from a financial point of view than the reference option.

In the high-price scenario, both LNG and LPG have payback periods in the 5-10 years range. As expected, the payback time decreases at higher vessel speeds since the investment costs are the same and the cost difference for each year of operation becomes more favourable by a higher fuel consumption, the effect is shown in Fig. 9. At 15 knots, the payback times are less than five years for all four variants.

The payback times are shorter for the one-fuel variants than for the mixed-fuel variants. As a result, the increased initial investments are more than compensated for by the lower prices for LNG and LPG compared to LSFO in the high-price scenario.

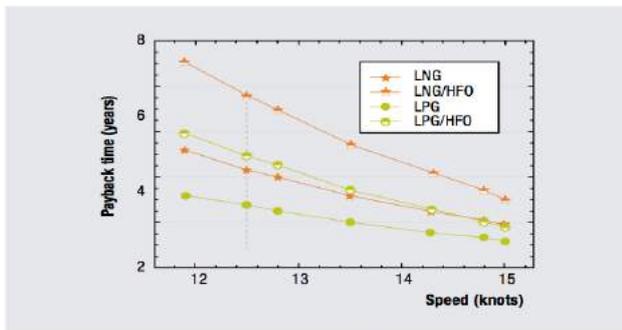


Fig. 9: Payback time as a function of ship transit speed for LNG and LPG pure and combined variants in the high price scenario (dashed line indicates reference speed)

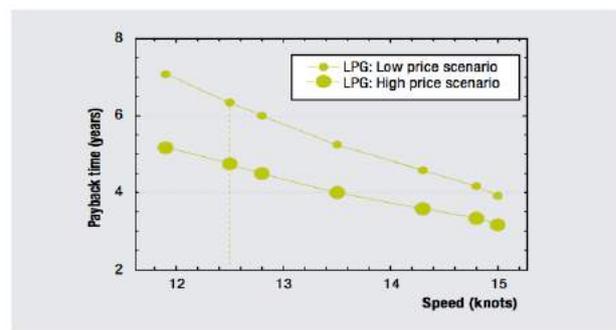


Fig. 10: Payback time as a function of ship transit speed shown for LPG in both price scenarios - LPG is used both inside and outside SECAs (dashed line indicates reference speed)

One-fuel variants show that LNG and LPG look attractive. Thanks to the lower added investment for LPG capable installations, LPG offers shorter payback periods, see Figs. 4 and 9.

In the low-price scenario, the payback time for LNG is more than the 13 years considered in this study, whereas LPG has a payback time of approximately 6.5 years. Payback times for LPG in both price scenarios are shown in Fig. 10. Based on the fuel price scenarios presented in this work, LPG can be understood as at least as good as LNG based on a shorter payback time, less sensitivity to reasonable price variations and less initial investments.

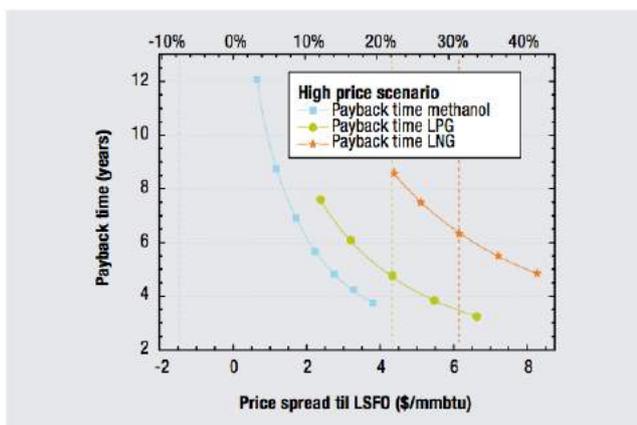


Fig. 11: Payback time as a function of price difference between LSFO (at 19.55 \$/mmbtu) and the alternative fuel (dashed lines represent the values used in the high price scenario for each fuel)

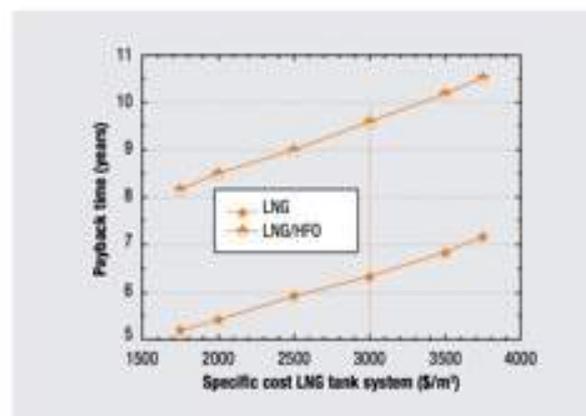


Fig. 12: Payback time as a function of specific tank cost for LNG, high price scenario (dashed line indicates reference value)

Sensitivity of fuel prices, LNG tank investment and bunkering choice

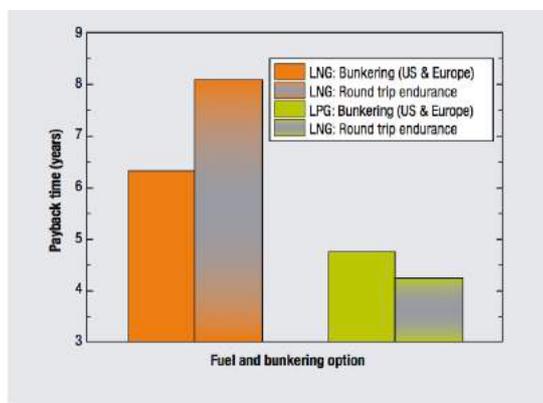
Fuel prices with their intrinsic uncertainty are critical for the outcome of the financial analysis. In addition, LSFO is not a common fuel today, and it is neither clear which refinery streams will be used to produce the LSFO, nor what the price level would be. A study carried out by Purvin & Gertz assumed that LSFO would be based on desulphurised atmospheric residue, and that the price would be 120-170 \$/t higher than HFO. In order to take the uncertainty into account, a sensitivity analysis between LSFO and the alternative as shown in Fig. 11, LPG requires a smaller discount than LNG to be financially attractive. This is due to a lower investment. Even though the expected discount is less for LPG than LNG,

the payback time is shorter. Nevertheless, with reasonable prices for LNG and LPG in the high-price scenario, the additional investment required due to the alternative fuel is paid back within the project period of 13 years.

If 0.5% LSFO is based on a distillate, MGO prices will likely increase at the beginning of the global sulphur cap. This is not included in our study, but since such increases would make the alternative fuel look better, our estimated payback times are considered conservative in this case.

The outcome of the financial assessment is also strongly dependent on the tank cost in the case of LNG. This tendency is shown in Fig. 12. For example, if the LNG tank investment was to be reduced to below 2000 \$/m³, including the foundation, the LNG-based variant would have about a year shorter payback time and be closer to the payback time of LPG, compared with Fig. 9.

In this study, a tank capacity for half a roundtrip was assumed, which means that the vessel would need to bunker in



Houston and in Rotterdam. However, there is a fuel price difference between the ports. Therefore, the scenario was also checked for bunkering LNG and LPG only in the cheapest location on the round trip, i.e. Houston. When LNG is used for the full round trip, the payback time increased from 76 to 97 months by reduction of bunkering to one location. Hence, the additional investment cost in a larger tank capacity is not returned by the lowered fuel price. However, for LPG the payback time is reduced from 57 to 51 months by installing the tank capacity necessary for a full round trip. The main reason for the difference is the high tank price for LNG compared to LPG

Fig. 13: Comparison of payback time for LNG/LPG bunkering for one location with full round trip endurance (Houston) or for bunkering in two locations for half round trip endurance (Houston and Rotterdam)

Conclusions

The interest in using alternative fuels is growing, and the first ships with dual fuel two-stroke propulsion engines have now entered service.

The fuel alternatives LNG, LPG, methanol and ULSFO have been compared to a reference case using traditional fuels (MGO/LSFO) as a means of sulphur compliance for a typical LR1 tanker trading between Europe and Northern America. The comparisons were made with two different scenarios of fuel prices. Generally, the scenario with the highest absolute fuel prices resulted in the highest price difference between traditional and alternative fuels. As a consequence, the high-price scenario resulted in the highest annual cost difference for the alternatives as well as the shortest payback times.

With the two price scenarios used in this study, methanol and ULSFO did not show a financial feasibility. LNG and LPG are both financially interesting alternative fuels, and LPG was found to be at least as good as LNG. For these best fuels, the best alternative is to use it both inside and outside SECA regions. For LPG, it is recommended to consider full round-trip endurance for the tank system.

3.8. Bunkering Methods

LPG bunkering can, in principle, take place in a number of ways, from terminals or trucks on shore or from bunkering vessels. Bunker deliveries from terminals to LPG-carrying ships are today handled safely with specialised training, and safety may be improved by using a bunkering ship as an intermediary between the terminal and the ship using LPG as fuel. Certainly, for deep sea shipping with significant amounts of fuel to be bunkered, a bunker vessel would be the preferred solution.

There are **different possible combinations** of bunkering vessels with pressurised tanks, semi-refrigerated tanks or fully refrigerated tanks, and similar arrangements in the ship to be bunkered.

Four cases illustrate some key bunkering challenges:

- ▶ In the case of **pressurised tanks** both in the bunkering ship and the ship to be bunkered, the LPG is transferred using a general transfer pump located in the bunkering ship. When filling the LPG tank, pressure will build up because of less gas volume available, and since it takes time to condense LPG, this can increase fuelling time. For practical purposes and to comply with safety regulations, the LPG tank must be equipped with a vapour return system back to the bunkering vessel, i.e. a gas outlet connection in addition to the liquid inlet connection. This case represents the most common and cost-effective LPG bunkering option.
- ▶ In the case of **semi-refrigerated tanks** in the bunkering vessel and a **pressurised tank** in the ship to be bunkered, it is necessary to have a heater and a booster pump in the bunkering ship and a vapour return system in the ship to be bunkered. The heater is needed because the fuel has a lower temperature than the tank design temperature, and this will typically be handled by a heat exchange system using heat from seawater. The LPG filled will have a lower than ambient temperature, but needs to be above the tank design temperature. The booster pump is needed to raise the pressure of the LPG before bunkering. Both the heater and booster pump are typically installed on semi-refrigerated LPG carriers, that may be used as bunkering ships. The vapour return from the ship to be bunkered may have too high a pressure for the semi-refrigerated tank, and must be handled by the re-liquefaction plant in the bunkering vessel, which may require some modifications. An alternative to vapour return in this case is to fill the cold LPG with a spray-line to condense the LPG vapour.
- ▶ In the uncommon case of **pressurised tanks** in the bunkering vessel and a **semi-refrigerated tank** in the ship to be bunkered, the pressure needs to be reduced by lowering the temperature in a liquefaction plant. An LPG carrier with pressurised tanks is typically not equipped with this, thus requiring comprehensive modifications of the equipment and cargo handling system. This case also requires a vapour return system with a compressor in the bunkering ship that needs to be set up to increase the pressure of the vapour return. LPG carriers with pressurised tanks are typically equipped with a compressor, but only for the purpose of emptying the cargo tanks.
- ▶ In the case of **semi-refrigerated tanks** both in the bunkering vessel and the ship to be bunkered, cooling (and probably not heating) may be necessary. A vapour return system and some modifications of the re-liquefaction plant in the bunkering vessel to ensure a higher capacity may also be necessary.

Based on the cases discussed above, a pressurised LPG fuel tank is the preferred solution when bunkering the ship, because the ship can be bunkered by a bunkering vessel based on an LPG carrier (either with pressurised tanks or semi-refrigerated tanks) without major modifications. Both types of bunkering vessels are possible, depending on the size of the fuel tanks to be bunkered and the number of ships to be served. Semi-refrigerated LPG carriers typically have larger capacity than pressurised LPG carriers and sufficient capacity for all ship types. They are also more flexible, e.g. in terms of filling ships with semi-refrigerated fuel tanks, and have a limited cost premium.

A key requirement for ocean carriers to adopt LPG as an engine fuel is the availability of LPG bunkering facilities.

LPG bunkering requires specialised infrastructure for supply, storage, and fuel delivery to ships. Depending upon the specific circumstances, LPG bunkering could require transporting LPG to a port from an offsite facility for temporary storage at the port, or building an LPG terminal on site. Alternatively, LPG could be delivered from offsite facilities directly to ships in port via road tanker or supply ship. There are three types of bunkering models:

- ▶ Truck (Road Tanker) to LPG Fuelled Ship (RTS).
- ▶ Shore (LPG Terminal) to LPG Fuelled Ship (PTS).
- ▶ Ship to LPG Fuelled Ship (STS).

The construction of LPG bunkering hubs is currently under development. The transport and handling of LPG as cargo on land and sea have been proven for many years.

The choice of bunkering options will depend on the regulatory framework, local conditions, cost and operational considerations. The type of vessel the size of the on-board fuel tank will to a great extent influence the bunkering method and the required transfer rate.

Vessel Type	LPG Tank Size (m3)	Bunkering Method
Workboat, Tug	ITB>100	RTS, Container
Ferries	100-200	RTS
OSV	>300	TPS, TTS
Ships	500-10,000+	STS

Typically, based on the LPG tank size the table summarises the preferred or practical bunkering methods.

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

STS transfers from LPG bunker vessels offer important advantages in terms of the ability to handle large volumes quickly, at a variety of locations.

Vessel Type			Existing Number of Vessels	Order Book	
				Vessels on Order	% of Fleet (# vessels)
Very Large Gas Carrier >60,000 cbm	Fully-Refrigerated		284	37	13%
Large Gas Carrier 40,000 - 59,999 cbm	Fully-Refrigerated		12	-	-
Medium Gas Carrier 25,000 - 39,999 cbm	Fully-Refrigerated Ethylene / Ethane		95 14	6 -	6% -
Handysize Gas Carrier 15,000 - 24,999 cbm	Fully-Refrigerated Semi-Refrigerated Ethylene		26 64 25	- - 8	- - 32%
Small Gas Carrier 5,000 - 14,999 cbm	Semi-Refrigerated / Pressure		332	16	5%
Small Gas Carrier <4,999 cbm	Semi-Refrigerated / Pressure		633	6	1%

Source: Clarksons, 2018

Source Epic Gas and IHS Markit

3.9. Main Players

The shipbuilding industry is embedded in a value chain consisting of designers, equipment manufacturers, yards, ship owners, operators and their clients, as well as supporting parties like classification societies and research institutes.

Each party has its specific role to play when it comes to developing new (green) ships. In some ship segments, owners or operators are having a strong say, while in others yards and equipment manufacturers appear to dominate.

European shipyards' competitive position vis-à-vis other world players can be characterised as a niche player active in high quality, high value segments. At the same time, European marine equipment manufacturers have succeeded to retain a strong position supplying not only European but also Asian shipyards.

Marine gas engines, gas burning or dual-fuel marine engines in both low- and medium-speed configurations are available from engine manufactures such as Wärtsilä, MAN B&W, and Rolls Royce (Bergen Engines).

Three brands have dominated the large two-stroke sector for main engines, MAN Diesel & Turbo, Mitsubishi and Wärtsilä but the latter has now transferred its business to a new company, Winterthur Gas & Diesel (WGD), initially as a joint venture with China State Shipbuilding Corporation before disposing of all its stake to its partner. Within the two-stroke sector MAN has a dominant market share and four out of five engines supplied in this sector today are MAN Diesels. Mitsubishi is considered as the smallest in terms of market share of the three companies.

Although both MAN and WGD can build these large engines, the number of engines built by licensees in China, Korea and Japan is much larger than that by licensors with Hyundai Heavy Industries claiming the lion's share. With support from its Chinese parent, WGD has ambitions to significantly improve its market share in the future.

3.10. Regulatory Framework

International maritime transport is the backbone of the global economy. However, vessels release emissions that pollute the air and contribute significantly to global warming. As shipping is forecast to grow, reducing these emissions is urgent, in order not to undermine emissions-reducing efforts in other areas, to keep humans healthy, preserve the environment and limit climate change. Although international shipping was not explicitly mentioned in the 2015 Paris Climate Agreement, efforts to make shipping cleaner and greener have since progressed. International



rules to reduce air-polluting emissions from ships have been agreed in the International Maritime Organization (IMO).



The IMO is the specialised agency acting on behalf of the United Nations (UN). IMO has the responsibility for international improvement of maritime pollution and safety standards. The

original guidelines for regulations to limit airborne emissions from international shipping resulted from the entry into force of the Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) in May 2005, MARPOL was adopted in its first state in 1973 by the IMO. As of 2010, the IMO tightened regulations on **air pollution**

(also termed 'local pollution') from ships with the revised International Convention for the Prevention of Pollution from Ships (MARPOL, Annex VI), aimed at a progressive global reduction in emissions of sulphur, nitrogen and particulate matter (PM). It also introduced special emission control areas (ECAs) with strict emissions limits for those pollutants. Two ECAs were established in European waters, covering the Baltic Sea and the North Sea.

Reduction of sulphur oxides (SOx) emissions is achieved by limiting sulphur content in marine fuels. The revised MARPOL planned for a reduction in the limit for SOx and PM in ECAs to 0.1 % from 1st January 2015. In areas outside the ECAs, the sulphur limit was to be lowered from the previous 3.5 % to 0.5 %. Once the availability of compliant fuels was confirmed in 2016, the IMO announced a global 'sulphur cap' of 0.5 % in all waters, apart from ECAs, from 1 January 2020. Later, it banned even the carriage of non-compliant fuels on board for ships without an exhaust cleaning system ('scrubber', see box on p.4), from 1st March 2020.

The IMO also introduced progressive reductions of nitrogen oxides (NOx), by setting increasingly stringent limits for marine diesel engines on new-built ships, structured in three levels ('tiers'). The currently strictest 'Tier III' applies to engines installed on ships constructed in 2016 or later, operating in ECAs controlling NOx. From January 2021, all ships in these areas must use the mandatory engine standards or equivalent NOx emission reduction technologies to respect the NOx emission levels. In 2016, the IMO added the Baltic Sea and the North Sea to the existing NOx Emission Control Areas.

In 2016, the IMO adopted a mandatory fuel data collection system ('**IMO DCS**') and, after mounting international pressure, an initial strategy on the reduction of GHG emissions from ships in 2018. The strategy aims to cut shipping emissions by at least 50 % by 2050, compared to 2008 levels, before phasing them out entirely. In parallel, the average carbon intensity (CO₂ per tonne-mile) should be reduced by at least 40 % by 2030 and by 70 % in 2050. To be reviewed in 2023, the strategy outlines candidate short, medium and long-term reduction measures, to be agreed by the IMO Marine Environment Protection Committee (MEPC). The short-term measures should achieve a peak in emissions as soon as possible and set them on a descending path. Clearly, measures to reduce air polluting emissions should not undermine efforts to reduce GHG emissions, and vice versa.

In addition to existing policies, there is potential for much greater climate mitigation from new IMO policies that promote efficient shipping technologies and practices. Additional policy progress to improve shipping technology beyond the current EEDI requirements and extend leading operational practices to the full fleet could stabilize shipping emissions at 2010 levels despite a significant increase in the demand for global goods transport. Such policies could reduce 0.4 GtCO₂, or 2.1 mbd, in 2030, equivalent to a 30% reduction in global shipping emissions.

3.10.1. Regulatory Framework in Recreational Craft Sector

Importance of EU-US standards, based on new technologies

There is a need to update and for further development of standards for boating, especially the EU. This is an ongoing, long and delicate process, but it is valuable to bringing together elements of the European (EN) and (US) system. Indeed, mutual recognition of base of acceptance of international standards (ISO) could be helpful, whereas mutual recognition of recreational craft's legislation could be detrimental for the EU as has not updated standards to include new developments in LPG marine outboard applications. The level playing field is different in the EU and the US.

Innovation

EU legislation has two effects; on the one hand strict environmental standards is a driving force to invest in cleaner engines. Europe's standards also help to protect water, which (in lakes and rivers water, keep oceans clean) compared to the rest of the world are stricter in most cases.

EU regulation

Small and medium enterprises have complained that EU norms stemming from the directives are only available in French, German and English. This means that many small companies with only a few boat builders from other EU member states may not always have the necessary language skills to understand specific EU norms and regulation.

Shipping – A Key European Industry

- ▶ International shipping is an essential part of European transport. **It carries 75% of external EU trade, and 36% of intra-EU trade.**
- ▶ Shipping is an essential link in the global supply chain, and a key part of the EU economy. It is also one of the most energy-efficient modes of transport available.
- ▶ The EU shipping industry directly employs around 640,000 people and up to 2.1 million when including the whole supply chain. The industry contributed nearly EUR 54 billion to the EU GDP in 2018.
- ▶ More than 400 million passengers embark or disembark each year at EU ports. Shipping contributes to coastal economies, and help bring Europeans closer together.
- ▶ The European maritime technology sector produces around half of the world's marine equipment each year. The EU remains a global leader in the construction of sophisticated, higher added value-vessels.

CO₂ emissions per ship type

- ▶ Ship types emitting the most CO₂ emissions are equally the biggest consumers of fuel.
- ▶ Container ships represented the largest share of total emissions in 2018, with over 30%. In absolute terms, these ships reported more than 44 million tonnes of CO₂, which is comparable to the CO₂ emissions of Ireland or Sweden. This pollution originated from only 1,742 ships that together reported over 5 million hours of time spent at sea.
- ▶ Bulk carriers that represent 37% of the monitored fleet (in cargo carrying capacity) emitted approximately 13% of all reported CO₂ emissions (17.5 million tonnes).

Total CO₂ emissions from different ship types and number of ships

- ▶ Taken together, the CO₂ emissions from oil tankers and chemical tankers amount to around 20% of all CO₂ emissions, whereas they transport more than a third of the cargo handled in the main EU ports.
- ▶ Ro-ro and ro-pax (roll-on/roll-off passenger) reported around 20 million tonnes of CO₂. These emissions are primarily related to domestic or intra-EU ferry services concentrated in the Baltics, the North Sea and the Mediterranean. It is estimated that over 415 million passengers embark and disembark in EU ports every year.

CO₂ emissions per ship age

- ▶ About 74% of total CO₂ emissions are produced by vessels built before 2013. Out of the entire monitored fleet, 8,840 ships fall into this category. Older vessels have the highest average level of CO₂ emissions per vessel, while younger ships constructed after 2013 emit less on average.

3.10.2. Regulatory Framework in Commercial Shipping Sector

With the current global trend towards a reduction of air emissions from all sectors, the shipping industry is experiencing increased pressure from stakeholders in general, and regulators in particular, to tackle its emissions and improve its energy efficiency. Emissions from shipping currently represent 3% of the world's total greenhouse gas (GHG) emissions, and the industry's share is increasing. A continued increase in international marine transport without any significant gains in energy efficiency may result in shipping being responsible for 6% of the world's GHG emissions by 2020 and 15% by 2050.

Shipping Emissions and Associated Impacts

In the current era of globalisation, the shipping industry has become a key component of the world's economy. Over 90% of global trade is carried by sea. The world fleet of sea-going merchant ships of more than 100 gigatons (GT) comprises over 104,000 ships.

Like other transportation companies, shipping companies require fossil fuel to conduct their operations. The combustion of fossil fuel used by a vessel's engines produces greenhouse gases (GHG) as well as non-GHG emissions.

GHG Emissions

Under the GHG Protocol, six gases are categorised as greenhouse gases: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorooctane sulphonate (PFCs), and sulphur hexafluoride (SF₆).²

- ▶ Carbon dioxide: CO₂ is the GHG most relevant to the shipping industry. Globally, 1,050 million tonnes of CO₂ were emitted by shipping in 2007, doubling 1990 levels. CO₂ emissions represent approximately 3% of the world's total CO₂ emissions.
- ▶ Other greenhouse gases: The shipping industry also emits other GHGs such as CH₄, N₂O, and HFCs. Annual aggregated emissions of these GHGs represent 21 million tonnes of CO₂ equivalent. Emissions of PFCs and SF₆ are considered negligible.

Non-GHG Emissions

In addition to GHGs, shipping produces other air emissions, most notably sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter (PM).

- ▶ Sulphur oxides (SO_x): The shipping industry is among the top emitters of SO_x. A total of 2.3 million tonnes of SO₂ (the most common sulphur oxide) was emitted by ships in the seas surrounding Europe in the year 2000. SO_x emissions from shipping represent between 5% and 8% of the world's total SO_x emissions.
- ▶ Nitrogen oxides (NO_x): Shipping also accounts for a significant portion of the world's NO_x emissions. A total of 3.3 million tonnes of NO_x was emitted by ships in the seas surrounding Europe in the year 2000. NO_x emissions from shipping represent around 15% of the world's total NO_x emissions.
- ▶ Particulate Matter (PM): In 2000, 250,000 tonnes of PM were emitted by ships in Europe. The amount of PM released by ships is much lower than that of SO_x or NO_x emissions. Note that PM and SO_x emissions are correlated: a decrease in SO_x emissions reduces emissions of PM.

Shipping emissions are an important contributor to several major environmental problems. GHG emissions contribute to climate change (i.e. longer term, less instantaneously visible effects), while non-GHG emissions can cause acid rain, damage to monuments, a reduction of agricultural yields, water contamination, modification of soil biology and deforestation (i.e. more short term, visible effects). Some non-GHG emissions are also linked to increases in ground-level ozone.

Shipping emissions can also cause negative social impacts. The effects of climate change, such as drought or rising sea levels, can lead to social conflict over resources (i.e., water, energy, agricultural products). Air pollution from non-GHG emissions can affect the heart and lungs, consequently worsening the condition of people with cardiovascular and

respiratory diseases. For instance, in Hong Kong, 519 premature deaths have been linked to marine SO₂ emissions.7 Additionally, non-GHG emissions can react chemically in the atmosphere to form particulate matter; prolonged exposure to which can affect a person’s mood and cognitive abilities. Another negative consequence of pollution is smog which can reduce the quality of life and inhibit the attractiveness of tourist sites.

The Legislative Context

Shipping emissions are expected to double by 2050, as are the related social and environmental effects. In order to mitigate environmental and social risks associated with these emissions, regulators around the world have started to act. Generally speaking, when it comes to reducing emissions and supporting energy efficiency, regulators deploy four primary policy mechanisms: emissions trading, financial incentives/taxes, emission reporting/monitoring obligations and energy efficiency/emissions standards. We will address each of these policy mechanisms and see how relevant they are for shipping companies. As the most prominent regulators in the shipping industry are the International Maritime Organization (IMO) and the European Union (EU), we will also look at the regulations set by these two bodies. Finally, we will examine the voluntary initiatives that have emerged in some countries.

IMO 2020 - five key changes



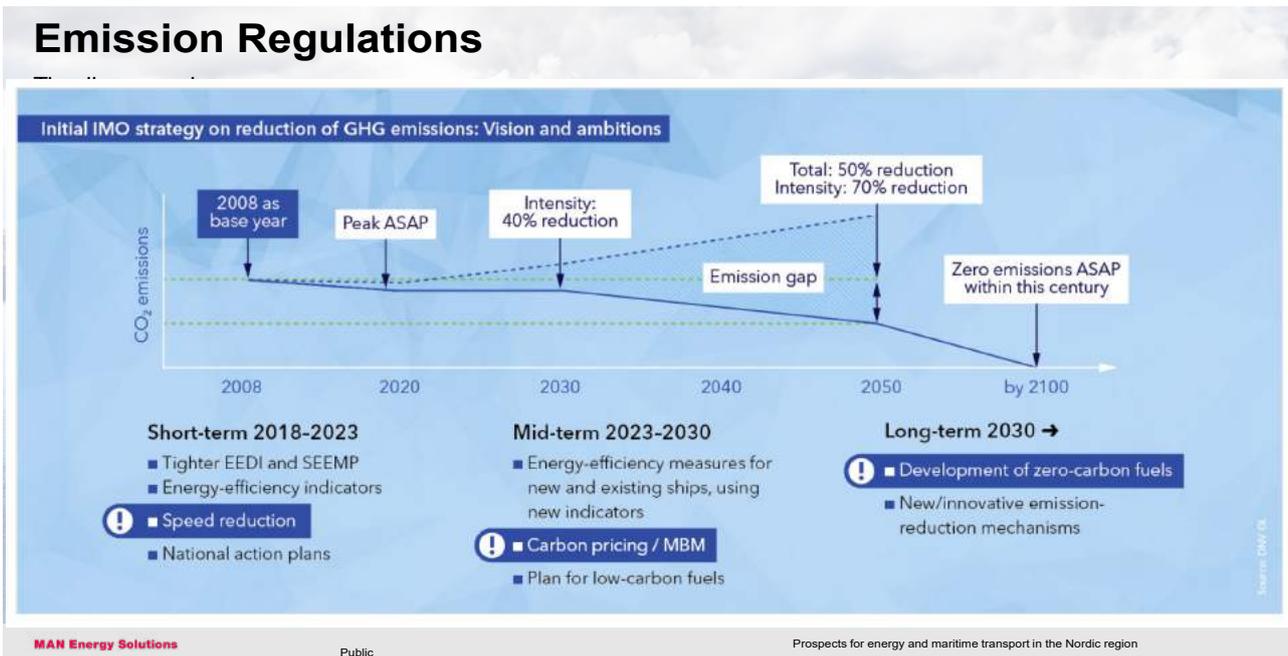
Limiting SO_x emissions from ships will have a very positive impact on human health

Limiting sulphur oxides emissions from ships reduces air pollution and results in a cleaner environment. Reducing SO_x also reduces particulate matter, tiny harmful particles which form when fuel is burnt.

Achieving the IMO decarbonisation goals

A study on the human health impacts of SO_x emissions from ships, submitted to IMO’s Marine Environment Protection Committee (MEPC) in 2016 by Finland, estimated that by not reducing the SO_x limit for ships from 2020, the air pollution from ships would contribute to more than 570,000 additional premature deaths worldwide between 2020-2025.





IMO’s strategy toward decarbonising defines three levels of ambition with two interim goals remaining: achieve a 40% reduction of the average carbon intensity by 2030 and a 70% reduction by 2050, compared to 2008 levels. The industry’s total GHG emissions are to be reduced by year 2050. The strategy is underlines by short, mid- and long-term ambitions. A quick short-term win is to begin reducing the shipping industry’s carbon intensity. This has been by introducing the Energy Efficiency Design Index (EEDI) for new ships and speed ship reductions an easy preliminary measure/successful implementation of the two remaining levels of ambition will depend on timely technological innovation and global availability of alternative fuels and/or energy sources. But technology alone will not be enough there is a need for international regulations that will create incentives for selecting cleaner fuels. The main focus should be on developing zero carbon fuels by 2050.

Pre-existing measures

In 1973, the IMO adopted the International Convention for the Prevention of Pollution from Ships (MARPOL). Originally orientated towards the prevention of oil pollution, MARPOL has developed since 1973 to deal with a broader range of ship-source pollution issues, including pollution by garbage, sewage, ballast water and stemming from the recycling of ships. MARPOL has also been developed to address pollution caused by GHG emissions and in July 2011, at the 62nd session of the MEPC, the IMO adopted the MARPOL Annex VI Regulations on Energy Efficiency for Ships (the Regulations).

The Regulations, which came into force on 1st January 2013, are the first rules to ever establish CO₂ standards across any global sector. They apply to existing and newly built vessels, although in different ways, and set out various energy efficiency measures which ships must comply with.

Existing ships

For existing ships, the Regulations require that all ships have a Ship Energy Efficiency Management Plan (SEEMP). This is a management plan for improving the energy efficiency of the ship by operational means, such as by optimising vessel speed, increasing the frequency of hull or propeller cleaning, or by making different route choices to reach a destination or pass-through heavy weather. Each ship’s SEEMP is specific to that ship and will take account of the factors particular to it, such as the cargoes carried, routes sailed and dry-docking schedule, as well as broader corporate or fleet level

strategies for improving efficiency. To support the planning process the IMO has developed a monitoring tool, the Energy Efficiency Operational Index (EEOI), which ship owners and operators can consult to gauge the potential impact of any management changes they may make and thus weigh up the options from a more informed position.

Owners and operators already have an incentive to increase efficiency, so as to reduce fuel costs. The SEEMP planning process bolsters this by placing firmly on the agenda an opportunity to consider new technologies and practices at every stage in the operation of the vessel. Thereby increasing the likelihood of their take up, and of increased efficiency gains which will benefit owners, operators and the environment.

New ships

For new ships, the regulations require compliance with the Energy Efficiency Design Index (EEDI), which takes a phased approach to setting minimum energy efficiency improvements for ships. The EEDI applies to most ship types and for each ship type and size a reference line, measured as grams of CO₂ emitted per tonne mile and based on the average efficiency of ships built between 2000 and 2010, has been set. The EEDI requires that energy efficiency is improved, in phases, such that CO₂ emissions are progressively reduced below the reference line.

The EEDI does not prescribe how the reduction of CO₂ emissions should be achieved, rather it leaves ship designers and builders free to innovate and to continue the technical development of all components of the ship which contribute to fuel efficiency.

During phase one, which ran 1st January 2015 to 31st December 2019, the EEDI required a 10% reduction of CO₂ grams per tonne mile below the relevant reference line for newly built ships. In phase two, running 1st January 2020 to 31st December 2024, the EEDI requires a further 10% reduction of CO₂ grams per tonne mile. Phase three of the EEDI, which was due to commence in 2025, requires an additional 10% reduction, meaning overall that ships being built in 2025 will be required to be 30% more carbon efficient than those built in 2000 – 2010.

In the seventy-fifth session of the Marine Environment Protection Committee (MEPC 75), which was held from 16 to 20 November 2020 as a web conference due to the pandemic of COVID-19 the following decisions taken to strengthening EEDI phase 3 requirements.

- ▶ For general cargo ships, LNG carriers and cruise passenger ships, the effective date is moved forward from 2025 to 2022 with the reduction rate of 30%;
- ▶ For containerships, the effective date is moved forward from 2025 to 2022 and the reduction rate is strengthened based on the ship sizes;
- ▶ For gas carriers (e.g. LPG carriers) with 15,000DWT and above, the effective date is moved forward from 2025 to 2022 with the reduction rate of 30%. For gas carriers (e.g. LPG carriers) below 15,000DWT, the current effective date of 2025 and the reduction rate are retained; For ship types other than the above, the current effective date of 2025 and the reduction rate are retained.
- ▶ Adjustment of the reference line for very large bulk carriers recognizing that EEDI requirements for very large bulk carriers as being too stringent, the amendments to MARPOL Annex VI to adjust the reference line for very large bulk carriers more than 279,000DWT were adopted. (Refer to Res. MEPC.324(75) as attachment 1).
- ▶ Introduction of possible EEDI phase 4 requirements MEPC 74 established a correspondence group (CG), coordinated by Japan, to consider the possible introduction of phase 4.

IMO resolution MEPC.304(72)

Initial IMO strategy on reduction of GHG emissions from ships

Level of ambition

Carbon intensity of ships to decline

- Strengthening of EEDI requirements for new ships

Carbon intensity of shipping to decline

- 40% reduction per transport work by 2030 relative to 2008
- 70% reduction per transport work by 2050 relative to 2008

GHG emission from shipping to decline

- 50% reduction of GHG emissions by 2050 relative to 2008

Timeline

Short-term measures: 2018–2023

- EEDI improvement (Energy Efficiency Design Index)
- SEEMP improvement (Ship Energy Efficiency Management Plan)
- Speed regulation
- Methane slip regulation
- VOC regulation (Volatile Organic Compounds)

Mid-term measures: 2023–2030

- Low-carbon/zero carbon fuels introduction
- Operational energy efficiency requirements
- Market-based measures

Long-term measures: > 2050

- Zero carbon/fossil-free fuels for 2050 and later

New measures

Pursuant to the publication of the initial strategy, the IMO is considering new short, mid and long-term measures for achieving its carbon intensity and GHG reduction ambitions.

Short-term measures are to be finalised by 2023. These are goal-based, include technical and operational measures, and are aimed at achieving the 2030 target of a 40% reduction in the carbon intensity of international shipping. Three types of short-term measures are under consideration:

- ▶ Those that can be considered and addressed under existing IMO instruments, these also include developments to pre-existing measures, such as the SEEMP and EEDI discussed above.
- ▶ Measures that are not work in progress and are subject to data analysis.
- ▶ Measures that are not work in progress and are not subject to data analysis.

Some of the candidate measures under consideration include existing fleet improvement programmes, speed optimisation and reduction programmes and measures to address the emission of methane and volatile organic compounds.

Mid- and long-term measures – mid-term measures are to be concerned with the period 2023 to 2030 and long-term measures with the period 2030 onwards. It is predicted that these measures will account for at least 50% of the change which needs to occur in order for the IMO to achieve its ambitions.

These measures are likely to require a high degree of innovation and to result in the global uptake of new fuels and new technologies. From 2023 onwards the IMO will start focusing its activities in these areas.

Candidate mid- and long-term measures include programmes to implement the use of low and zero carbon fuels, programmes to develop and provide zero carbon or fossil free fuels, further operational efficiency measures and market-based measures, such as emissions trading, emissions related levies and emissions offsetting.

Impact on shipping

The IMO's GHG emission reduction measures impact ship owners on a number of fronts. For some time already, ship owners have been required by the Regulations to plan for and manage ship efficiency, and have been supported by the IMO to explore the available options and their likely impact. However, the tweaking and refining of current practises

and technologies will only take the industry so far towards the IMO's goals. A major shift in technologies, especially in fuel preference, is envisaged by the initial strategy.

Additionally, the industry can anticipate that significant behavioural changes, such in 'just in time' arrivals at ports, are likely to either be required or more strongly incentivised in the future, so as to become widespread and normalised. These too will play a key role in accomplishing the targets set by the IMO.

With much still unknown there is perhaps a tendency to hang back on implementing new technologies and practices while owners and operators wait to see which have high take-up and are proven to be trouble free and effective. In the meantime, it is likely that retrofitting will play a major role in moving the industry towards accomplishment of the IMO's goals. Meaning that technologies which are designed to be adapted in several different directions in the future may become popular in the short-term as the industry hedges its bets on the global preference for future fuels.

Whatever the future may be, it is evident that an appreciation of rising efficiency standards, the targets for future reduction of GHG emissions, and the trajectory of the industry towards cleaner shipping, must inform the decisions made by owners and operators today if those parties are to future proof their investments and to achieve financial efficiency, as well as efficiency at sea.

Upcoming

One criticism levied at the global regime advanced by the IMO is that it is simply not progressing fast enough. Despite shipping's global nature, the EU was recently prompted by the IMO's pace of change to take its own action in relation to GHG emissions from shipping, voted in July 2020 for emissions from shipping to be included in the EU's Emissions Trading Scheme (EU ETS) with effect from 2023.

In summary, the key ambitions of the initial strategy are:

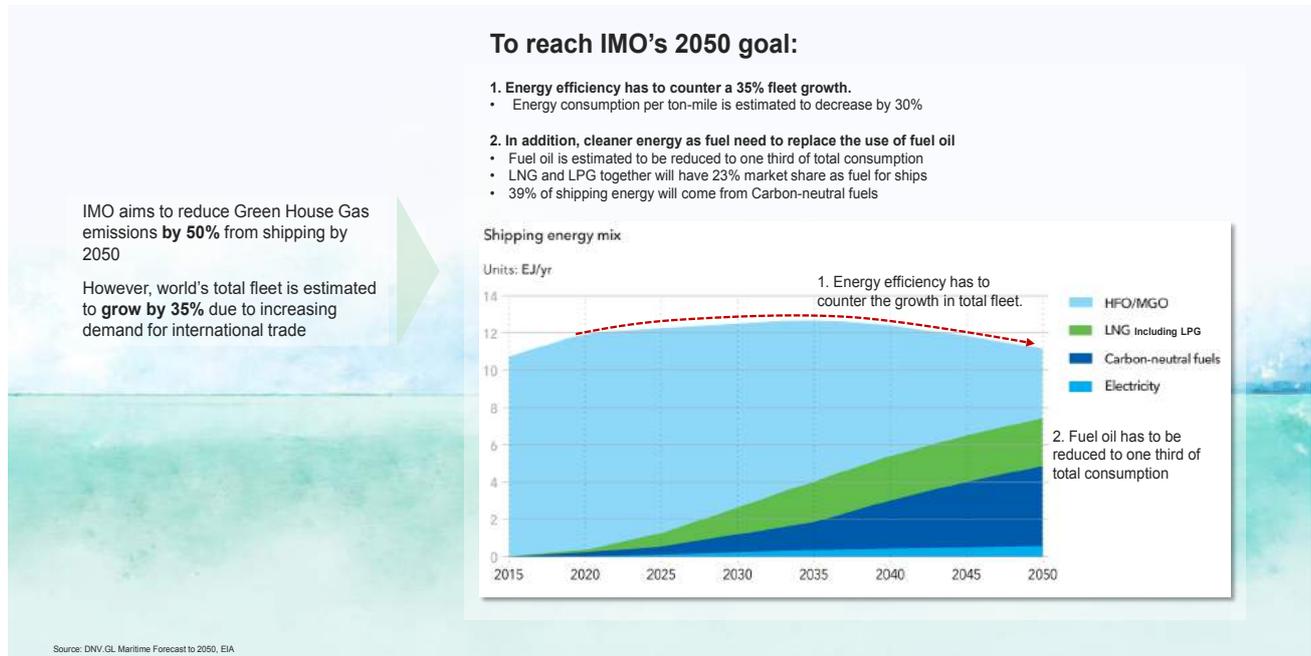
- ▶ To reduce the carbon intensity of international shipping, compared to 2008 levels, by 40%, by 2030.
- ▶ To increase that reduction to 70% by 2050.
- ▶ To reduce GHG emissions from international shipping, again compared to 2008 levels, by at least 50%, by 2050

To achieve zero GHG emissions as soon as possible within this century, ie by 2100.

The IMO is working to achieve these ambitions by way of a mixture of means, including pre-existing energy efficiency measures and new measures applicable in the short-, mid- and long-term.



Gas is an alternative to reach IMO's 2050 emission goal



The deal seems to mirror the terms being sought by the government of Norway, but is far less than what the Marshall Islands and the European Union had been aiming for. Those parties had reportedly been aiming for carbon emissions reductions of between 70–100% by 2050 (as compared to 2008 levels). These new rules have far reaching implications for the international shipping trade, the cruise industry, and ship owners and operators in particular.

Of particular note are regulations in Emissions Control Areas (ECAs) such as the North American ECA, which went into effect in 2012, and the Sox Emission Control Areas (SECAs), which have been in effect on the Baltic Sea and North Sea and English Channel since 2006 and 2007, respectively. On 1st August 2012, enforcement of the North American ECA commenced. The North American ECA covers the coastal waters of the United States and Canada out to 200 nautical miles. Ships operating in the ECAs and SECAs are required to use lower-sulphur fuels or add sulphur oxide (SOx) exhaust scrubbers. Regulations for a Caribbean ECA will go into effect for Puerto Rico and the U.S. Virgin Islands. Allowing for the lead time associated with the IMO process, the U.S. Caribbean ECA became forceable in January 2014. There is the potential that ECAs will be established for the **Norwegian and Barents Sea, Mediterranean Sea, Japan, Australia, Mexico and Panama, the Arctic, and Antarctica** in the future. The rules for these areas will mandate reductions in emissions of sulphur (S), nitrogen oxides (NOx) and particulate matter (PM).

ECAs with nitrogen oxides thresholds are denoted as Nitrogen Oxide Emission Control Areas (NECAs).

Certain maritime regions are designated emission-controlled areas (ECAs) where the regulated emission levels are lower than in the rest of the ocean. Accordingly, regulations of air pollution from ships are only effective for certain aspects of the present shipping activities. **The regulations will become tighter in a stepwise manner and additionally, the number of emission control areas will potentially increase.**

Sulphur limits for fuel in SECA	
before 1 July 2010	1.50% m/m
between 1 July 2010 and 1 January 2015	1.00% m/m
after 1 January 2015	0.10% m/m

General sulphur limits in other sea areas	
before 1 January 2012	4.50% m/m
between 1 January 2012 and 1 January 2020	3.50% m/m
after 1 January 2020	0.50% m/m

There are two grades of marine fuel allowed in the SECA area: Low Sulphur Heavy Fuel Oil (LSHFO) with maximum allowed sulphur content of 1.0% by mass and Low Sulphur Marine Gas Oil (MGO

DMA) with maximum sulphur content of 0.1% used in European inland waterways and in ports in the (SECA) area (The European Parliament and the Counsel of the European Union 2005).

In 2013, the Energy Efficiency, Design Index (EEDI) entered into force, becoming the first regulation to establish CO₂ emission standards across a global sector. EEDI essentially requires new ships to be progressively more efficient from 2015 through 2025, as compared against the average 2000-2010 ships of the same type. For non-CO₂ pollutants, 2014 saw the successful implementation of the newest emission control area (ECA), the US Caribbean Sea ECA, to regulate NO_x and SO_x emissions. ECAs are sea areas that are specially designated by the IMO for enhanced mandatory measures to control air pollution from ships, including maximum fuel sulphur content and exhaust NO_x emission levels (IMO, 2014). Today, ships traveling in ECAs must meet stricter fuel sulphur requirements than elsewhere; and as of 2016, new ships were required to meet special NO_x emission standards (Tier 3) when traveling within ECAs. Following Russia's proposal to delay the implementation of Tier 3 NO_x standards in ECAs, the IMO upheld the 2016 implementation date for existing ECAs (including the US Caribbean ECA), but delayed this date for NO_x ECAs entering into force in later years.

Legislation for Marine SO_x Reduction

New and existing regulations derived from the International Convention for the Prevention of Pollution from Ships (MARPOL) affecting the SO_x emissions from ships are summarised in Table 1.

Table 1. MARPOL Annex VI Marine SO_x Emission Reduction Areas with Fuel Sulfur Limits

	Year	Fuel Sulfur (ppm)	Fuel Sulfur (%)
European SECAs			
North Sea, English Channel	Current Limits	10,000	1
	2015	1,000	0.1
Baltic Sea	Current Limits	10,000	1
	2015	1,000	0.1
North American ECAs			
United States, Canada	2012	10,000	1
	2015	1,000	0.1
Global	2012	35,000	3.5
	2020 ^a	5,000	0.5

^a Alternative date is 2025, to be decided by a review in 2018.

Legislation for Marine NO_x Reduction

In addition to having to meet the fuel sulphur limits in Table 1, ships operating in the ECAs must meet the MARPOL Annex VI Marine Tier III NO_x limits of 2016.

Table 2 shows the applicable NOx limits for ships and the dates that they became effective.

Table 2. MARPOL Annex VI NOx Emission Limits (Source: Ref. 9)

Tier	Date	NOx Limit, g/kWh		
		$n < 130$	$130 \leq n < 2000$	$n \geq 2000$
Tier I	2000	17.0	$45 n^{-0.2}$	9.8
Tier II	2011	14.4	$44 n^{-0.23}$	7.7
Tier III	2016 ^a	3.4	$9 n^{-0.2}$	1.96

^a In NOx Emission Control Areas (Tier II standards apply outside ECAs).

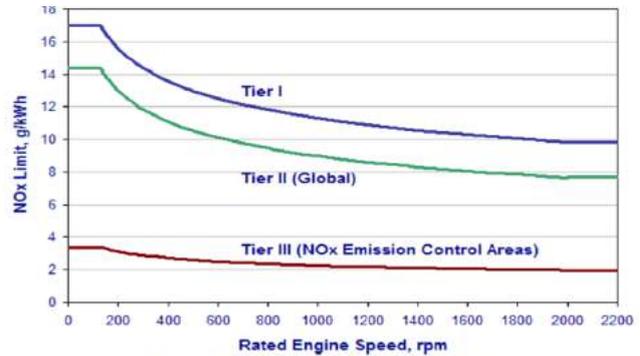


Figure 4. IMO Diesel Engine NOx Emission Limits

NOx emission limits are set for diesel engines according to engine maximum operating speed (n , rpm), as shown in Table 2 and presented graphically in Figure 4. Tier I and Tier II limits are global, whereas the Tier III standards apply only in the NOx ECAs. Tier III NOx limits apply to all ships constructed on or after 1st January 2016, with engines over 130 kW that operate inside an ECA-NOx area.

Compliance with Marine SOx and NOx Legislation

Given the proliferation of the ECAs and the possibility that more ECAs, such as in the Mediterranean Sea and the coast of Mexico, may come into being in the future, there is a strong incentive for ship owners and operators to explore the use of alternative fuels to satisfy the lower fuel sulphur and NOx limits.

Alternative Marine Fuel Incentives

Currently, there are a number of incentives for using alternative fuels. These include the following:

- ▶ The MARPOL Annex VI SOx and NOx legislation.
- ▶ The price fluctuations of fossil fuels.
- ▶ The prediction of a diesel fuel shortage in Europe .
- ▶ Current ECAs with their SOx and NOx limits .
- ▶ The proliferation of ECAs, with the possibility that future ECAs may come into force in the Mediterranean Sea and off the coasts of Mexico and Singapore (which has, in fact, requested an ECA).

The introduction by IMO in MARPOL Annex VI of the Energy Efficiency Design Index (EEDI), which would make mandatory some measures to reduce emissions of GHGs, such as CO₂ from international shipping. The EEDI standards phase-in from 2013 to 2025. The EEDI creates a common metric to measure and improve new ship efficiency. This metric is calculated as the rate of CO₂ emissions from a ship. Alternative fuels that can help satisfy the above requirements and having certain attributes can possibly be substituted for the fossil fuels currently in use.

Future course of action towards the abolition of Heavy Fuel Oils

- ▶ The global 0.5% sulphur cap was introduced in 2020, and up to **70,000 ships** may be affected by the regulation according to IMO estimates.
- ▶ The European Union Sulphur Directive stipulates a maximum 0.5% sulphur content for ships in all EU waters by 2020, and a 0.1% limit in ports. In certain EU countries, it should also be noted that the Water Framework Directive is putting constraints on the discharge of scrubber water.

- ▶ Belgium and Germany have in essence prohibited the discharge of scrubber water in most areas, severely constraining the operation of open-loop scrubbers. Other EU countries are following suit to a lesser or greater degree, with no common EU practice likely to be agreed.
- ▶ Currently Hong Kong has a 0.5% sulphur limit for vessels at berth.
- ▶ China has recently published regulations for domestic SECA-like requirements in the sea areas outside Hong Kong/Guangzhou and Shanghai, and in the Bohai Sea. China is taking a staged approach, initially requiring maximum 0.5% sulphur content in fuel burned in key ports in these areas, gradually expanding the coverage, and culminating in applying the requirements to fuel used in the sea areas from 2019 onward. There is the possibility that the requirement was tightened to 0.1% in 2020, and that a formal ECA application may be made to IMO.
- ▶ California's Air Resources Board (ARB) enforces a 0.1% sulphur limit within 24 nautical miles of the Californian coast. The regulation does not allow any other compliance options than low sulphur marine gas or diesel oil (DMA or DMB). A temporary research exemption may be granted allowing the use of a scrubber. The application has to be sent before entering Californian waters

Their impact, in particular the application of stricter limits for sulphur content in marine fuels since 1st January 2020, is yet to be evaluated. Parallel efforts to reduce greenhouse gas (GHG) emissions from maritime shipping have resulted in the setting of rules on collecting data on fuel oil consumption and the first collected data becoming available. In 2018, the IMO adopted an initial strategy for reducing GHG emissions, aimed at cutting shipping GHG emissions by at least 50 % by 2050, compared to 2008 levels. While concrete steps are yet to be agreed, achieving this goal will require both short-term emission-reducing measures and longer-term measures to make shipping switch to alternative fuels. On the EU front, the European Commission announced in the European Green Deal that GHG from EU transport should be cut by 90 % by 2050 and outlined how this would involve shipping. This briefing reviews the existing international and EU rules on shipping emissions and their application, looks into the short-term measures under discussion and maps the landscape of marine fuels and technologies that could help decarbonise shipping in the long term.

Regional sulphur limits vary

Open loop scrubbers utilization banned areas keep expanding



Map of areas where the use of open loop scrubbers is banned



- Since October 2019, 4 areas have banned the use of open loop scrubbers in their waters: Panama canal, Malaysia, Suez Canal, Karachi (Pakistan)

The European Union Sulphur Directive stipulates a maximum of 0.10% sulphur content for ships in EU ports. In certain EU countries, the Water Framework Directive constrains the discharge of scrubber water. Belgium and Germany have prohibited the discharge of scrubber water in many areas, constraining the operation of open-loop scrubbers. Other EU countries may follow suit, with no common EU practice likely to be agreed.

In China, as of 1st January 2020, vessels operating in the Inland ECAs (Yangtze and Xijiang River) shall use fuel with a sulphur content not exceeding 0.10% sulphur. The same will apply within the Hainan Coastal ECA from 1st January 2022. In addition, discharging wastewater from scrubbers is banned within inland Emission Control Areas (ECAs), port waters and the Bohai Bay waters.

California's Air Resources Board (ARB) enforces a 0.10% sulphur limit within 24 nautical miles of the California coast. The regulation does not allow any other compliance options than low-sulphur marine gas or diesel oil (DMA or DMB). A temporary research exemption may be granted, allowing the use of a scrubber. The application must be sent before entering California waters. After a formal review of the regulation, California legislators have decided to retain it as an addition to the ECA requirements. Both sets of regulations must be complied with when calling at port in California.

There is a general global trend of stricter local air pollution regulations coming into play.

European initiatives

The EU has plans to move 30% of road freight travelling over 300 km to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050.

Tracking EU maritime CO₂ emissions

During the first reporting year, the system involved:

- >11,600 ships**
 - Around two-thirds are non-EU flagged
 - More than half are owned by entities based in the EU.
- >2,000 companies**
 - Around half of these are European companies.
- 29 accredited verification companies**
 - Four verification companies have issued 62% of all documents of compliance. Three out of these originate from the EEA.

Maritime transport – a substantial CO₂ emitter

- >138 million tonnes of CO₂ in 2018**
 - Over 3% of total EU CO₂ emissions
 - Comparable to the CO₂ emissions of Belgium
 - According to projections, CO₂ emissions from maritime transport are likely to grow in the future, reinforcing the need for CO₂ reduction efforts.
- >44 million tonnes of fuels consumed**
 - 70% heavy fuel oils, which is a residual fuel and a heavy pollutant
 - 20% marine gas oil and diesel
 - 3% Liquefied Natural Gas (LNG)
 - Represents around 90% of total marine fuel sales in EU ports.

2019 Annual Report on CO₂ Emissions from Maritime Transport

Most CO₂ emissions come from voyages outside the European Economic Area

The EU Leadership initiative aims at ensuring the future of European shipbuilding. Decarbonising the shipping sector would involve not only introduction of greener marine fuels, but also innovative green and energy-efficient ship designs. Apart from this, **development of infrastructure and greening of the ports are in process.** However, introduction of alternative marine fuels will be

The Target: max. 1.5°C

MAN Energy Solutions

The Target: max. 2°C

CO₂ Emissions & Fossil Fuel Reserves

MAN Energy Solutions

accompanied by additional complexity in the areas of fuel supply infrastructure, rules for safe use of fuels on board and operation of new systems. Additionally, adoption or wide acceptance of these new fuels could possibly be a challenge for ship-owners. To ensure confidence that the technologies will work as intended, technology qualification from neutral third parties is needed. Among the stakeholders, ship owners and shipping agents will also play a major role in this transition. Although marine fuel standards are set in ISO 8217, all responsibilities for the fuel quality and quantity lie with the ship owners, with little to no liability towards the fuel suppliers or bunker parties. The choice of fuel lies primarily with the charterer (the shipping agent) who, in principle, rents the vessel from a ship owner. Hence, while considering new marine fuels, all these stakeholders must also be included.

3.11. Safety

Safety issues and standards for the use of LPG need to be addressed before this becomes more acceptable by the shipping industry.

An important property of LPG is that when in vapour form, it is heavier than air and when it leaks it always falls to the ground. If an LPG leak in a vessel is left un noticed, it will find its way to the engine room floor or bilge.

The preferred way of storing LPG for use as propulsion fuel is in a pressurised tank at ambient temperature. Storage in a semi-refrigerated tank made of cheaper steel types than for LNG is also possible, but in order for such an arrangement to be sufficiently reliable, back-up systems must be in place to ensure low temperature in the tank. This makes pressurized tank storage a more reliable, affordable and simple solution.

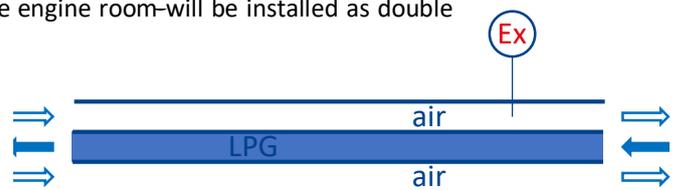
LPG has a higher density than air and any spillage will collect in lower spaces, requiring a different approach to leak detection and ventilation in the case of leaks. LPG is also known as an “extremely flammable gas” with flammability limits between 1.0 vol% and 12 vol% in air. LPG is a low-flash-point liquid, and when used in a high-fire-risk space of the ship with a constant personnel presence, like in the engine room, a double-walled pipeline must be used as secondary containment. Hydrocarbon detectors will detect any leakage and contain the fuel within the secondary containment before it reaches areas where humans are present.



Double-walled pipelines must be used below the deck line.

Summarising the following mitigating measures are required to ensure all risk are as low as reasonably possible:

- ▶ The entire LPG fuel supply and conditioning system will be installed on main deck, in the already existing hazardous area.
- ▶ The piping with LPG at 50 barg to be minimised in length as much as possible to limit the inventory and will be fully welded.
- ▶ Additional gas detection will be installed in the bottom of the engine room.
- ▶ All piping containing LPG liquid or vapour installed in the engine room-will be installed as double walled piping.
- ▶ The annular space will be flushed and monitored continuously for any leakages.
- ▶ In case of any potential safety issue in the LPG fuel supply system, the emergency shutdown system of the vessel will automatically cause the main engine to switch over to compliant fuel oil.
- ▶ The LPG fuel system will be subjected to a risk-based assessment. A HAZID and HAZOP study will be performed.



The auto ignition temperature for LPG (490°C) is lower than for LNG (580°C), which may require a lower surface

temperature near electrical equipment. Compared to LNG, LPG has fewer challenges related to temperature because it is not kept at cryogenic temperatures but on the other hand it has challenges related to the higher density as a gas and a lower ignition range, with a lower explosion limit of about 2%. The challenges are different, but **overall, the safety management is probably somewhat simpler for LPG than for LNG.**

The development of any new technology requires uppermost attention and consideration of safety implications and especially so if the new technology involves engines and equipment, machinery, and/or vessels that use LPG as a fuel.

LPG, same as any other fuel, can be entirely safe as long as the equipment is designed correctly with all safety aspects considered and the operation is equally carried out in the same manner. New technologies require thorough assessment of all potential safety risks.

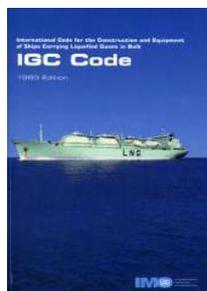
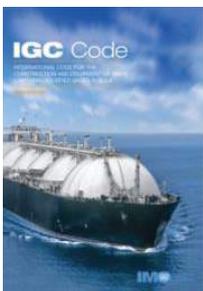
Particularly in the marine environment, three main factors need to be considered: **Corrosion issues, vibration and constant movement of the vessel.**

The use of corrosion resistant alloys and stainless steel, galvanising and appropriate coatings are commonly used in the marine environment. The additional cost of utilising these materials will be outweighed by the potential damage caused by not applying them and the need to replace components.

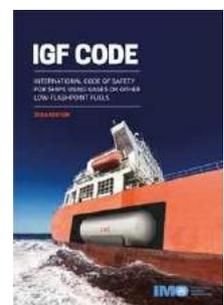


In addition, the consequential impact of failure when out on the water could be disastrous.

Regarding safety issues, the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code 1983 edition – as amended IGC Code 2016 edition) and International Code of Safety for Ships using



Gases or other Low-flashpoint Fuels (IGF Code) was adopted by the Maritime Safety Committee (MSC) by resolution MSC.391(95), in order to provide an international standard for the safety for ships using low-flashpoint fuel, other than ships covered by the IGC Code. The IGF Code is made mandatory under amendments to chapters II -1, II -2 and the appendix to the annex of the International Convention for the Safety of Life at Seas (SOLAS), 1974, that were adopted by the MSC at the same



session, by resolution MSC392(95) (entry into force: 1st January 2017).

The adoption of the IGF Code was the culmination of over ten years of work by several IMO bodies, starting with the approval by MSC78 (May 2004) of a work item on “Development of provisions for gas-fuelled ships”. Following the adoption by MSC86 (June 2009) of the Interim Guidelines on safety for natural gas-fuelled engine installations in ships (resolution MSC.285(86)), MSC 87 approved the expansion of the scope of the work on development of provisions for gas-fuelled ships to include ships fuelled by low-flashpoint liquid fuels. The present version of the IGF Code includes regulations to meet the functional requirements for natural gas fuel. Regulations for other low-flashpoint fuels will be added as, and when, they are developed by the organisation.

This Code provides an international standard for ships using low-flashpoint fuel, other than ships covered by the IGC Code. The basic philosophy of this Code is to provide mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuel to minimize the risk to the ship, its crew and the environment, having regard to the nature of the fuels involved.

Overall, the safety management is probably somewhat simpler for LPG than for LNG.

3.12. Training

Training of personnel in new technologies, new equipment and particularly in areas where safety is of prime concern is



a key. This is the case when LPG is introduced as a new alternative fuel in any equipment and operations.

Adequate training is a prerequisite before any such new engine and equipment is put into service. International training is a key

3.13. Quality of Fuel

The manufacturers of all types of engines for marine and especially for outboard uses have specific requirements for the quality of the fuel used in their engines.

Modern equipment and advanced technologies come most often with increased requirements as far as the quality of the fuel is concerned. The same holds for LPG and in particular even more so when this is used in marine engines that need to provide continuous and reliable service.

Fuel quality requirements accordingly differ. Otto or spark ignition fuels must be resistant to detonation when compressed in a flammable mixture with air and should burn smoothly without prematurely igniting.

For marine outboards, high technology adopted by the last generation of such engines (very high power in a compact and very light unit) added to the need of high-efficiency, means high compression ratios join with very advanced fuel strategies, in many cases with sophisticated lean-burn technology. For this type of engine, the LPG quality must be high because any damage to the power unit can be a source not only of very high maintenance cost, but can also affect the safety of the boat users themselves due the marine environment.

Currently the quality of LPG used as an outboard engine fuel can vary significantly from country to country.

There are certain key conditions and features of the LPG fuel quality that can be considered as extremely critical and if respected and well controlled, they can ensure problem free performance of a modern outboard engine.

The low Sulphur levels in LPG fuel are needed for the new engine technologies, like the injection of LPG and the lean burn injection strategies.

In LPG, odorants used for safety reasons contain sulphur compounds that can increase the sulphur content in LPG by 5 to 20ppm and even more if not controlled correctly. As a result, having LPG as an acceptable competitive alternative fuel for today's gasoline and CNG/LNG fuelled marine engines, the right "formula" can be based on the U.S. HD5 standard, with low Sulphur (% by volume):

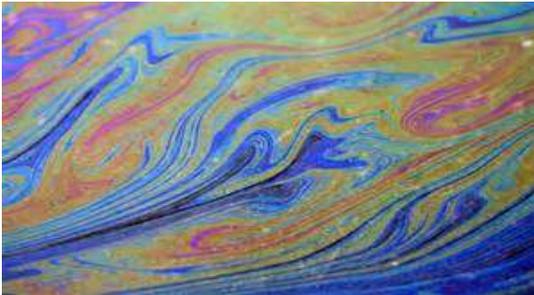
- ▶ Propane: 93% min
- ▶ Butane: 3.5% max
- ▶ Propene/propylene: 3% max
- ▶ Other Olefins: 0.5% max
- ▶ Sulphur: 50 ppm max (Limit adopted in many countries)
- ▶ Filtered out (not contaminated by plasticizers, rust particulates, sodium dioxide, water and other dirt)

Such LPG composition can ensure more than 101 Octane and can be an excellent fuel to be adopted by marine engine manufacturers as a reliable fuel for the last generation of high efficiency, very low emissions engines.

3.14. Environmental Aspects

The environmental argument to convert from gasoline and diesel to LPG is strong because Cargo boats, speed boats and fishing boats are frequently found on inland waterways, rivers and lakes where any form of fuel pollution can cause serious consequences to wild life, fish and the local environment.

Any spillage of gasoline and diesel will float on top of the water. The visual impact of a fuel spillage can be disturbing and lasting. Fuel spillages are most likely to occur during the refuelling or bunkering operation. The movement of a boat connected to a refuelling hose is challenging enough but if the refuelling is being done from a floating fuel barge, or bunkering barge, it is even more so. There have been several incidents involving fuel spillages from bunker barges over the years and most have resulted in some form of environmental damage. LPG fuel tanks are much less messy to refuel.



The result of an oil spillage on water

Another benefit of an LPG marine engine is its quietness compared to a diesel engine which operates at high higher compression ratios leading to increased noise.

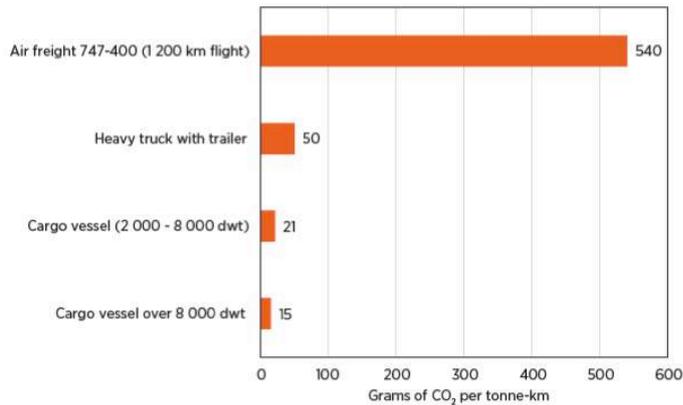
Protection of the environment and improvement of air quality is an important objective of the regulators today.

Emissions from the marine transport sector contribute significantly to air pollution globally and in 2013 marine transport accounted for 2.7% of global CO₂ emissions. These emissions are expected to increase by a factor of two to three by 2050 if no measures are implemented. Shipping particulate matter (PM) emissions have already been linked with approximately 60,000 cardiopulmonary and lung cancer deaths annually worldwide.

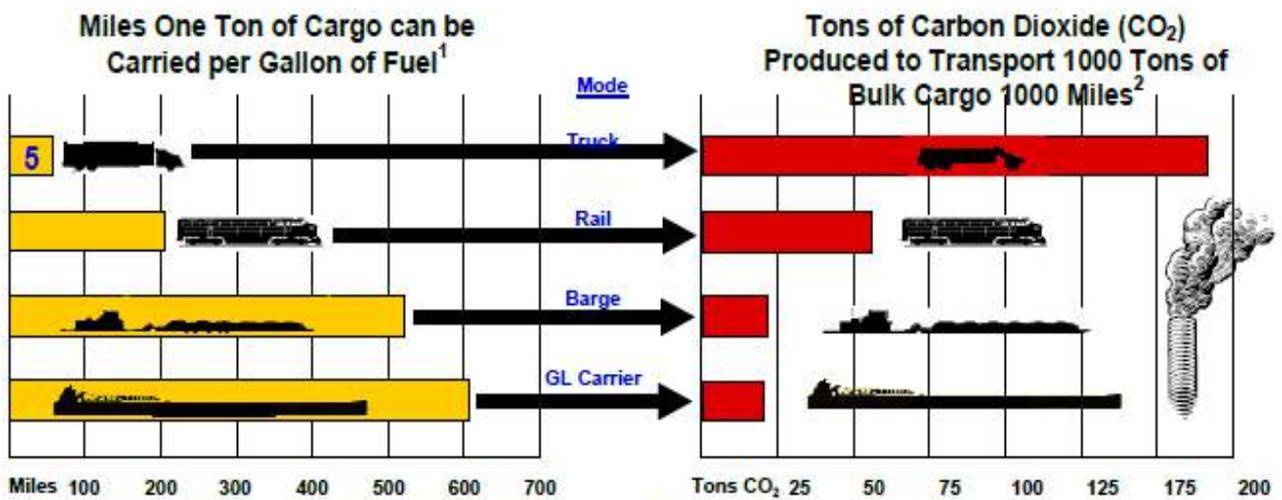
Maritime transport of goods is a relatively clean form of transportation per kilogram of material, but also an efficient mode requiring 2-3 grams of fuel per ton*km, compared to road transport by truck which is about 15 grams of fuel per ton*km.

When ships cross bodies of water, they leave behind visible “tracks” of pollution. NASA has been using satellite imagery

to collect data on ship tracks, and the results are disturbing.

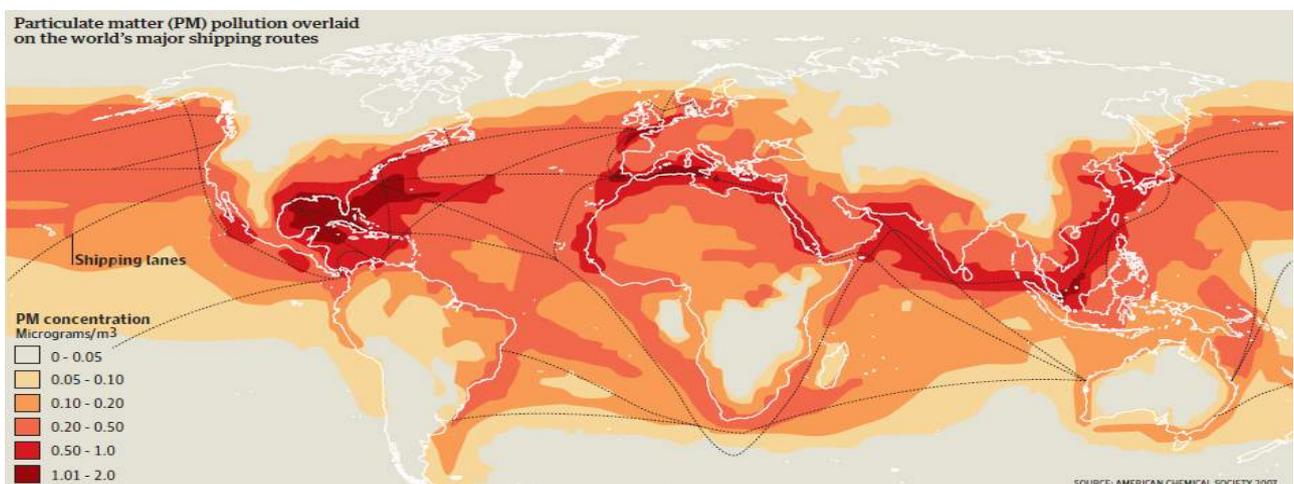


CO₂ emissions of different transport modes (Mofor, Nuttall and Newell, 2015)



1. Source: USDOT Maritime Administration and Minnesota Department of Transportation
2. Assumes US DOE Fuel and Energy Emission Coefficient of 22.38 lbs of CO₂ per gallon (No.1,2,4 Fuel Oils and Diesel)

Source: Greener Shipping in North America. DNV February 2011

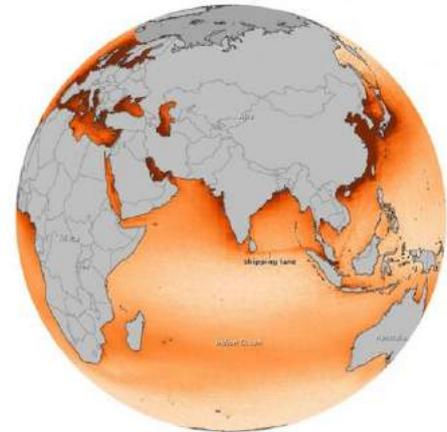


The image above shows only nitrogen dioxide (NO₂) emissions, and is a composite of data collected by the Ozone Monitoring Instrument on NASA’s Aura satellite from 2005 through 2012.

For more than a decade, scientists have observed “ship tracks” in natural-colour satellite imagery of the ocean. These bright, linear trails amidst the cloud layers are created by particles and gases from ships. They are a visible manifestation of pollution from ship exhaust, and scientists can now see that ships have a subtler, almost invisible, signature as well.

Data from the Dutch and Finnish-built Ozone Monitoring
Particulate Matter pollution overlaid on the world’s major shipping routes.

Source: American Chemical Society 2007



Instrument (OMI) on NASA’s Aura satellite show long tracks of elevated nitrogen dioxide (NO₂) levels along certain shipping routes. NO₂, is among a group of highly-reactive oxides of nitrogen, known as NO_x, that can lead to the production of fine particles and ozone that damage the human cardiovascular and respiratory systems. Combustion engines, such as those that propel ships and motor vehicles, are a major source of NO₂ pollution.

The map above is based on OMI measurements acquired between 2005 and 2012. The NO₂ signal is most prominent in an Indian Ocean shipping lane between Sri Lanka and Singapore, appearing as a distinct orange line against (lighter) background levels of NO₂. Other shipping lanes that run through the Gulf of Aden, the Red Sea, and the Mediterranean Sea also show elevated NO₂ levels, as do routes from Singapore to points in China. These aren’t the only busy shipping lanes in the world, but they are the most apparent because ship traffic is concentrated along narrow, well-established lanes. The Atlantic and Pacific Oceans also have heavy ship traffic, but OMI doesn’t pick up NO₂ pollution tracks because the shipping routes are less consistent. The shapes of landmasses force ships into narrow paths in the Indian Ocean, while ships in the Atlantic and Pacific tend to spread out over abroad areas as they navigate around storms.

In addition, the air over the north eastern Indian Ocean is relatively pristine. Heavy NO₂ pollution (dark red in the map) from cities and off-shore drilling activity along the coasts of China, Europe, and the United States obscures the ship tracks that might otherwise be visible to OMI. In the map, the Arctic is grey because the lack of light during the winter and frequent cloudiness during the summer prevented OMI from collecting usable data in the area.



Urban areas and industrialisation are not the only source of NO₂ in the map. Agricultural burning in southern Africa and persistent westerly winds make an elevated band of NO₂ that stretches from southern Africa to Australia. (In central Africa, easterly winds push pollutants from fires toward the Atlantic, keeping NO₂ levels comparatively low over the northern Indian Ocean.) Lightning, which produces NO_x, also contributes

to background NO₂ levels.

Research suggests that shipping accounts for 15- 30% of global NO_x emissions; scientists are using satellite observations to reduce the uncertainty in such estimates.

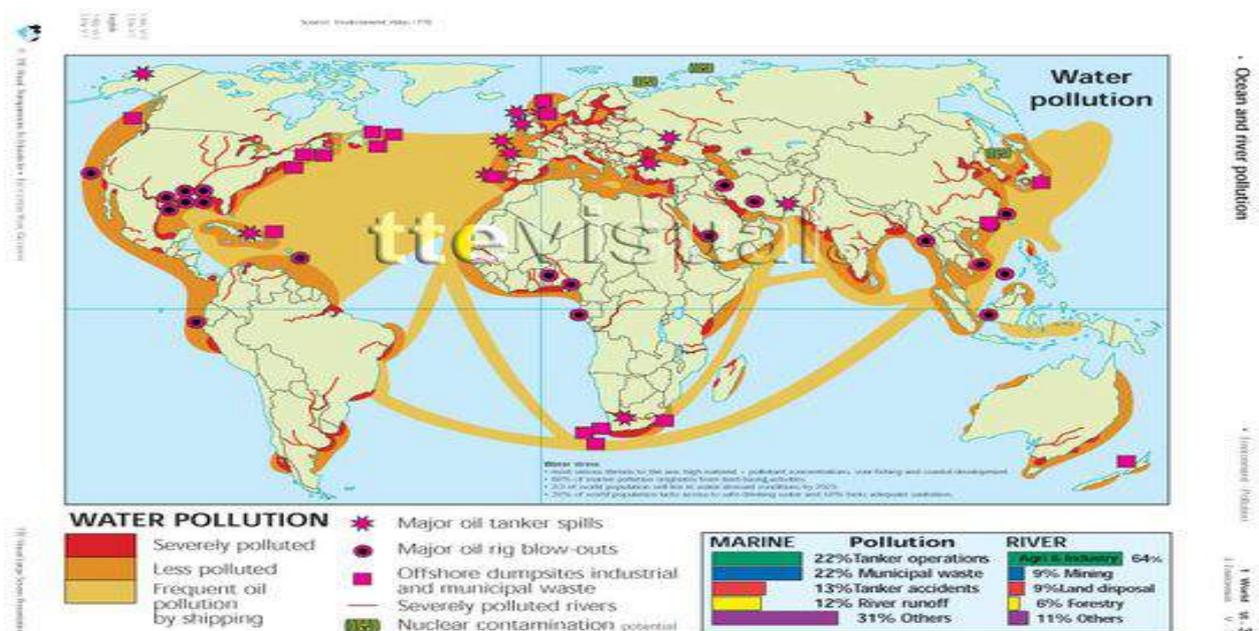
OMI is not the only satellite instrument observing NO₂ levels in the atmosphere. The Global Ozone Monitoring Experiment (GOME) instruments on the European Space Agency’s ERS-2 and MetOp-A satellites, as well as the SCIAMACHY instrument on the Envisat satellite, have made similar measurements. In 2012, Dutch scientists

published a study combining data from all four instruments to show that the NO₂ signal over major shipping increased steadily between 2003 and 2008, then dropped sharply due to the global recession and reduction in ship traffic.

Within Europe, 40,600 km of inland waterways and intra-EU maritime transport are used with inland navigation accounting for 1.6 % of final energy consumption in the transport sector.

Emissions from this sector contributes to 1-7% of ambient air PM10 levels, 1-14% of PM2.5, and at least 11% of PM1 and 4-6% of PM2.5 in Seattle. In some non-European harbours, contributions have been reported for example of <5% of PM2.5 in Los Angeles Contributions to ambient NO₂ levels range between 7-24%, with the highest values being recorded in the Netherlands and Denmark. In many coastal areas of Europe, it was estimated that ships were responsible for more than 50% of sulphur release, which could contribute to the formation of acid rain. This is mainly because traditionally the shipping industry has used fuels with high sulphur content, purchased at a price lower than that of crude oil.

The future of marine engines to ensure sustainability and global acceptance, requires the development of systems that reduce the dependence on oil and minimise the emission of greenhouse gases. Decarbonisation, reliability and safety



are the drivers for marine market development. Complying with environmental standards and requirements will entail however costly technologies, for which fleet and other operators may be unwilling to pay the price. The significant price advantage against diesel and abundant supplies of LPG reinforces the notion that LPG marine engines can play an important role as a major part of a clean fuel portfolio for the years to come towards reductions of GHGs, NO_x and PM emissions and near zero emissions objectives in particular combined with hybrid technologies.

3.15. Main Stakeholders

The role of the various stakeholders is instrumental in driving growth of LPG in the marine market, supporting product commercialisation and raising customer and policymaker awareness.

Key stakeholders include:

- ▶ Design offices.
- ▶ LPG marine engine manufacturers.

- ▶ Shipyards.
- ▶ Classification societies.
- ▶ Ship owners, cargo owners, ship operators.
- ▶ Policy makers, regulators, governments.
- ▶ LPG industry, LPG distributors.
- ▶ National and international LPG industry associations.

The main stakeholders in the shipbuilding **value chain** are shown in the below figure. Each stakeholder can play a specific role in the innovation process.



Others interested in promoting a cleaner, less expensive LPG fuel include flag State administrations, port State control authorities, underwriters, shipping financiers, charterers, and seafarers.

3.15.1. Design Offices

Design offices can play an important role as the conceptual design is crucial for a vessel’s operational efficiency. They usually collaborate with shipyards to develop a ship design which matches the operational criteria set by either the yard or the owner. In some cases, large ship owners/operators undertake design activities.

Design offices (possibly in cooperation with research institutes, classification societies but also R&D and design divisions of other actors along the value chain) can play an initiating role in certain innovations. Designers also increasingly cooperate with marine equipment manufacturers to take part in joint development projects. Whether these innovations find their way on the market depends on their interaction mainly with the ship owner and/or shipyards. A general risk aversion of ship owners to new innovation that are not yet proven technology is an impediment.

On the other hand, shipyards may embrace new designs (or develop them internally) as it allows them to differentiate from competing yards.

In some cases, marine equipment suppliers (especially larger suppliers) set up partnerships with other companies or universities/research institutes to develop specific techniques or technologies that target medium- or long-term developments.

The role of marine equipment suppliers towards ship owners and shipyards differs, depending on the cooperation model that is followed. In complex ship types, in general a more intense cooperation is sought between key actors across the value chain, while in more standard designs the role of marine equipment manufacturers may be less pronounced. In certain cases, ship owners strongly influence the choice of equipment suppliers as the operational cost or performance perspective of a ship is more important to them than to a shipyard.

For retrofit technologies, the role of marine equipment providers in innovation is essential as they can become a more direct contract party to the ship owner. Larger sized marine equipment manufacturers such as MAN and Wärtsilä are actively present in shipbuilding countries outside Europe and also engage in research cooperation with yards located there.

Box 2.2 Cooperation between Korean industries and European manufacturers

Focus on energy efficiency in South Korea has increased with R&D into dual fuel systems and cooperation with both MAN and Wärtsilä. The Korean based engine builder Doosan states to supply one of every four large ships built worldwide. Doosan’s roots came from license agreements with both MAN and companies now part of Wärtsilä. A great variety of R&D projects between yards and engine manufacturers, also involving other suppliers and Korean Register, are expected to deliver energy improvements for wide power output ranges.

Source: Marine Propulsion, August/September 2011, p.141-148

Moreover, several marine equipment actors are evolving towards a different business model in which maintenance or life cycle support becomes more important than pure direct product sales. This is often combined with a higher level of system integration in which systems (e.g. propulsion systems) rather than individual components are offered. Examples of this development can be found at companies like Rolls Royce, Wärtsilä, and Imtech. This development can partly be seen as a response to the economic crisis, but also as a business strategy to create a more permanent market position towards their clients.

A large number of small and medium enterprises are found in the marine equipment industry. Their number has been estimated between 5,000 and 7,000 companies in Europe. Typical problems faced by SMEs across industries, such as the difficulty of obtaining financing and moving from R&D to implementation, are also identified in this segment. An SME survey across a number of sectors indicated that “financing research and innovation activities” is their most important R&D and innovation need.

Whereas the innovation potential of marine equipment manufacturers is seen as high, they are also faced with specific barriers in bringing their innovation to market. This is partly the result of barriers that affect the driving forces behind green innovation in shipbuilding (e.g. regulatory uncertainty), but also due to conflicting interests and risk allocation/aversion of ship owners and operators.

3.15.2. Marine engine manufacturers

LPG dual fuel engine is already in the market but Natural gas marine engines (CNG/LNG) could easily be converted to LPG with better results regarding emissions.

Wärtsilä was the early pioneer to develop the first dual fuel medium-speed engines able to run on either fuel oil or LNG with the engines planned for use in LNG carriers. Today most of the leading engine manufacturers have incorporated dual-fuel versions of some engines into their portfolios although Rolls-Royce has opted to go with either diesel or pure gas versions of its Bergen engine range.

Existing LPG engines

Gas Marine Engine Manufacturers	
	<p>Caterpillar Marine Power Systems: Offers the MaK™ M 34 DF, a new marine dual fuel engine platform for the commercial marine industry</p>

	Cummins: Offers marine engines with a broad range of power 5.9 to 95 litres for commercial, government and recreational applications. Cummins has great experience in diesel and natural gas engines in oil and gas business.
	Doosan Engine: Offers low speed diesel/gas power plants.
	MAN: Offers gas marine engines for power generation in the 7 MWe to 21 MWe size range. MAN Diesel & Turbo has introduced a Liquid ME-LGIP (liquid gas injection) engine, which is powered by LPG.
	Niigata Power Systems: Offers dual fuel engine used two-type of fuel, oil and gas. Niigata developed the propeller direct drive type dual fuel engine which can meet the desired load operation characteristics coming from the tugboat which works in harbour without generating abnormal combustion such as a knock, with original combustion technology. Sudden acceleration torque and slowdown torque are required of a tugboat at the time of navigation of a large-sized ship.
	Rolls-Royce Power Systems: Through the MTU and Bergen brands, RRPS offers gas engines across the sub-250 kW to 10 MWe size range. Rolls-Royce developed the Bergen K (including KVG5 -12G4) gas engine. The gas engine has been designed and implemented to burn natural gas (Rolls-Royce). The MT30 is Rolls-Royce's gas turbine and was selected for the US Navy's DD(X) multi-mission destroyer (Corkhill) in a CODAG system (Rolls-Royce), and is considered the most power-dense solution available with ratings of over 40MW. The MT30 is ABS certified and intended for larger LNGCs. However, the MT30 gas turbine has not yet been modified to burn natural gas as a primary fuel. Rolls-Royce states that one of the benefits of its gas engine and turbine solutions for marine vessels is the need to only have one bunker fuel - LNG.
	Wärtsilä: A manufacturer of larger gas engines in the 10 to 20 MWe size range, with a number of reference plants that could use LPG as a fuel. Wärtsilä DFDE engines include the 50DF, 46DF, 34DF, 31DF, 32DF and 20DF. Wärtsilä is the only manufacturer with a known tri-fuel technology. The 50DF engine can burn LFO, HFO, and NG. The technology utilizes the "lean-burn" combustion principle that leads to a high compression ratio. Other benefits of the DFDE system while burning natural gas include no visible smoke from the vessel's smokestack and no sludge deposits. The 34DF and 32DF are dual-fuel technologies (Wärtsilä2). The 32DF is the engine that Wärtsilä markets for its passenger cruise-ferry concept. The primary fuel for the 32DF system is natural gas (LNG) and the backup (and pilot) fuel is MDO.
	WinGD: A leading developer of low-speed Gas and Diesel engines used for propulsion power in merchant shipping. These engines are utilized for the propulsion of all types of deep-sea ships world-wide, such as oil and product tankers, bulk carriers, car carriers, general cargo ships and container ships. The company continues the long tradition of the Sulzer Diesel Engine business founded in 1898. The company offers a wide range of low-speed diesel and low-pressure dual-fuel engines, covering all merchant ships applications from small cargo vessels to VLCCs and mega containers. WinGD's portfolio covers a power, bore and speed range from 2.5 to 73.5 MW, 350 to 920 mm and 58 to 167 rpm, respectively.
	YANMAR Co.: Offers dual-fuel engine for vessels that enables the user to switch to and from liquefied natural gas (LNG) and diesel fuel during operation.
Outboards Engines	
PROPEL	PROPEL: Offers LPG outboard marine engines from and 2.5- to 90hp
	Mercury: Offers LPG outboard marine four stroke engines 5hp
	Selva: Offers LPG outboard marine four stroke engines up to 50hp
	Tohatsu: Offers LPG outboard marine engines 5hp
	Yamaha: Offers LPG outboard marine engines 5hp
Gas Engine Management Solutions and Retrofit Systems Manufacturers	
	HEINZMANN: Offers engine and turbine management solutions; dual-fuel retrofit systems for a wide range of diesel engines to be converted to gas operation and at the same time providing all the safety features required for marine applications.

3.15.3. Shipyard

In relation to innovation, shipyards take a position in the role of system integrator, combining innovations from third parties/marine equipment suppliers in an integrated ship design and construction, and are a driving force behind new ships designs and innovations in response to market demands and in view of enhanced (fuel) efficiency. The frequency and intensity of innovations is strongly influenced by the level of standardisation of the ship types that are being produced (mass production versus one-off ship types).

In Europe, working in specialised (high value) niche markets in general involves an active innovation strategy (as many ships are one-off and build on demand of clients). The technological advance enables these specialised shipyards to retain their market position. IHC for example employs a roadmap to determine the innovations they will pursue, taking into account market foresights, different functionalities that can be realized with the innovation, and life-cycle opportunities. They mainly pursue process innovations as the integration of several techniques for a yard is key to obtain a competitive advantage. These yards for instance set up collaboration programs with marine equipment companies, universities and research institutes to study the behaviour and characteristics of ships. The presence of these actors in a certain geographical area is seen as an advantage to build up valuable knowledge and may limit knowledge leakage to other parts of the world. Also, marine equipment suppliers indicate the importance of having high class shipyards in Europe in their role as integrators and proving new concepts developed by marine equipment manufacturers before exporting equipment.

3.15.4. Classification Societies

The purpose of a classification society is to provide classification and statutory services and assistance to the maritime industry and regulatory bodies as regards maritime safety and pollution prevention, based on the accumulation of maritime knowledge and technology.

Classification societies are important as they set standards and supervise rules in the shipbuilding industry. In principle, class societies check whether the products and systems on board of a ship comply or not. They set and apply technical standards relating to the design and construction of ships and carry out extensive surveys of ships and their main systems. The largest classification societies are Det Norske Veritas (DNV), Lloyd's Register, Germanischer Lloyd, Nippon Kaiji Kyokai, RINA and the American Bureau of Shipping (ABS).

Recently however, classification societies have started to take a more active role in the introduction of innovations in the area of greening ships. Det Norske Veritas, for example, jointly with Japanese shipyard Oshima Shipbuilding Co., started the Eco-Ship 2020 project aiming at a bulk vessel design with 50% less weight and powered by LNG. Lloyds Register is doing a similar research with Shanghai based Bestway Marine Engineering Design. Furthermore, they have started to partner in other R&D projects as they possess a lot of specific knowledge, potentially pushing innovations slightly. Lloyd's Register for instance presented some of the approaches that can be used to safely apply and integrate rapidly advancing (green) technology on board ships. Specific attention was devoted to their work that is concentrated on application of alternative fuels and future energy sources, such as LPG and fuel cells.

Where traditionally classification societies are called upon to decide if the end product complies with the class rules, they are now moving up the value chain. They increasingly engage with design offices, ship yards and marine equipment manufacturers to discuss innovations and developments that contribute to raising the ship's fuel efficiency or reduce its operating costs. While they may become drivers of innovation when following this track, they should carefully address the balance between their commercial interests and their regulatory task.

3.15.5. Ship owners, Cargo owners, Ship operators

Ship owners are the main decision makers in the shipbuilding industry value chain. They are the ones that take the

purchasing decision and consequently the decision power to invest (or not) in innovations. Obviously ship owners also decide where to invest. In 2008, European ship owners accounted for over half (52%) of the entire demand for new build ships (whereas the share of European shipyards in the total global order book value at that time amounted to 13%). However, with the rise of Asian shipping companies it can be expected that there will be a shift in origin of ship owners in favour of Asia.

Especially in view of the current shift from a seller to a buyer market the position of ship owners has further increased. Potentially this allows ship owners to exert a major influence on the innovations that will enter a ship. They can determine the type, and often also the brand, of engines and other specific marine equipment and thus approve the application of innovations with regard to these items. The level to which they are interested to invest in green innovations is strongly dependent on their own business model and decisions (e.g. capex versus opex, CSR, self-operating versus chartering, etc.). As such they are strongly influenced by the green drivers that have been identified earlier. At the same time, they are strongly influenced by barriers like the uncertainty of fuel price developments, split incentive schemes, regulatory uncertainty, risk aversion toward technologies that are not proven, etc. The risk aversion of ship owners towards new technologies seems to be valid for banks financing their new build orders.

Shipping companies are the actual users of the ships to transport goods, people or to provide other services. In the case of passenger vessels, dredgers and offshore ships, the ship operator often coincides with the ship owner. This implies that there is one less decision power in the value chain, which is considered beneficial to the introduction of new innovations: the ship owner is affected by the investment costs but also by e.g. the fuel costs, making it easier to convince them to install innovation for example to enhance energy efficiency and reduce operating costs.

In other segments, notably bulkers and container ships, ship operating companies are rarely also the ship owners, but the two different parties have different incentives, e.g. ship owners are mainly concerned with investment costs, whereas the ship operating companies have to bear the fuel costs. For a marine equipment manufacturer, this involves negotiations with two parties with very different incentives, making the introduction of innovations more difficult and/or resulting in the ship operating companies not being represented in the construction process.

Cargo owners select a particular shipping company to ship their goods. A major factor in this decision is cost. However, recently a 'green' argument has gained importance and is now also influencing the decision of some cargo owners. For example, some cargo owners demand that their goods are being transported on a 'green' ship. This implies that the cargo owner can put pressure on the ship owners to do an effort in 'greening' the ships and thus allow innovation to happen.

Some marine equipment manufacturers have discovered the power of cargo owners. A new strategy for them is to approach the cargo owners in addition to the ship owners, to provide them with information regarding new innovative products or systems. If the cargo owner has an interest in the new product or system, it helps them to sell this to the ship owner. In this way, marine equipment manufacturers are creating a demand pull (from the cargo owners), creating a powerful argument to convince the ship owner to invest in their innovative offer.

Ship owners have an essential role to play in creating the new infrastructure for LPG as marine fuel. Without a demand from ship owners to use LPG as fuel, no new infrastructure will be possible. The LPG infrastructure requires a sufficient amount of investment in new LPG-fuelled ships or the conversion of existing shipping to use LPG marine fuel. The first adopters must be prepared to assume the risk of possibly choosing the wrong technology due to the current uncertainty of future costs of using LPG compared to fuel oils and other alternatives.

Before ship owners will invest in LPG-fuelled vessels, they are likely to demand the following conditions:

- ▶ The price of LPG as marine fuel must be competitive compared to HFO and cleaning solutions.

-
- ▶ The availability of LPG must be reliable. LPG bunkering infrastructure must be available in most, if not all, ports used by the ship owner (assured availability).
 - ▶ The regulatory framework should be clear regarding design, operations and emissions.
 - ▶ Tried and tested bunkering procedures must be in place. The question of whether LG bunkering can be undertaken simultaneously with cargo handling must be answered—bunkering must not cause delays or result in longer stays in port.

3.15.6. LPG Distribution Companies and Associations

LPG distribution companies play the most crucial role in developing this market. If these do not invest and engage in implementation in projects related to supply and bunkering infrastructure it is not possible for a project to be successful.

To gain larger entry to the marine market, LPG associations may have to convince decision makers of LPG's operational, commercial and safety advantages. LPG industry associations have to inform all stakeholders about the benefits of LPG, offer to their members the opportunity to exchange views on the upstream and downstream parts of the LPG business as well as facilitate engagement with marine engine manufacturers by regularly organising interactive meetings and in-country workshops between technical experts, senior members and key stakeholders. They need to support the development and harmonization of standards in designing, bunkering and the operational process of a marine vessel.

3.15.7. Policy Makers, Governments, Regulators

Clear, consistent, and efficient regulatory frameworks are an essential requirement for the deployment of any new technology. In the case of marine LPG fuel transition, it is particularly pertinent, since the marine sector is subject to a complex regulatory environment with overlapping jurisdictions that range from local to global.

When lines between diverse regulatory bodies blur, it often leads to significant barriers for industry. This situation is a key barrier facing LPG marine deployment globally and government must be encouraged to set clear regulatory guidelines that are essential in achieving broader and fleet-wide conversions.

Governments can assist this process by accelerating technology demonstrations and R&D funding, to improve marine LPG technologies and enhance operational learning. The areas where policy action would be most valuable are in addressing the regulatory and commercial barriers, which are slowing the development and deployment of cleaner marine technologies, even when the business case is strong.

Germany's Federal Ministry of Transport and Digital Infrastructure (BMVI) is to offer grants for companies building or retrofitting ships to use LNG as a fuel.

The incentives are open only to new projects and for ships that will comply with IMO's Tier III NOx limits. The ministry is in the process of drafting the first call for proposals, through which ship operators and owners will be able to apply for the grants. The grants are available to fund equipment for new ships with propulsion systems using LNG either as part of a dual-fuel or pure gas configuration, or for the conversion and replacement of conventional diesel engines for pure gas or dual-fuelled operation. Gas-fuelled auxiliary systems, such as boilers, can also be funded. The incentives are intended to support the introduction of LNG as a marine fuel in Germany, diversify the country's fuel base and deliver the environmental and health benefits of switching to less polluting fuels.

3.15.8. Other Societies

In the marine sector, there are some societies that can play an active role in the introduction of innovations in the area of greening, safe ships.

- ▶ International Association of Classification Societies (IACS).
- ▶ Marine engine manufacturers (MAN, Wärtsilä etc.).
- ▶ Society of International Gas Tanker and Terminal Operators (SIGTTO).
- ▶ Society for Gas as Marine Fuel (SGMF).

3.16. Engagement of Main Stakeholders

Coordinated engagement of the stakeholders is important to work towards the key objectives: Cultivate ship owner, shipping companies, cargo owners, and government awareness of LPG as an exceptional energy source. The LPG industry must work vigorously to create and maintain a high level of awareness regarding LPG's unique benefits.

Case studies

- ▶ The technology group Wärtsilä is to supply the engines for a new LNG fuelled research vessel being built for the German government. The vessel is under construction at the Fassmer shipyard in Germany and will be owned by Bundesamt für Seeschifffahrt und Hydrographie (BSH), the Federal Maritime and Hydrographic Agency. The contract was signed with Wärtsilä in June 2017.
- ▶ The new 75m ship, the 'Atair' will replace her 30-year-old namesake, and will be the first German research vessel operating on LNG fuel. The full scope of Wärtsilä's supply for the 'Atair' is two six-cylinder Wärtsilä 20DF dual-fuel engines capable of running on either LNG or conventional liquid fuels, one six-cylinder Wärtsilä 20 engine, two exhaust cleaning systems, and a Wärtsilä LNGPac fuel storage, supply, and control system. The engines will have Tier III classification since the dual-fuel engines comply with this classification when running in gas mode, and all the engines will be compliant when operating on diesel because of the Wärtsilä SCR systems.

3.17. Market Status

LPG as fuel is now a proven and available solution. In 2020 the industry hit a significant milestone with four LPG-fuelled ships in operation. The number of ships using LPG as fuel is increasing fast and more and more bunkering projects are planned or proposed along the main shipping lanes.

Total of 79 engines on order (April 2021)

2018 - EXMAR: 10 x 80,000m³ VLGCs
 2019 – Equinor: 3 x 38,553m³ LGCs
 2019 - Tinjin S.W.Southwest Maritime (TSM): 5 x 86,000m³ VLGCs
 2019 - Kumiai Navigation: 4 x 84,000m³ VLGCs
 2019 - Geogas: 2 x 91,000 VLGCs
 2019 - Avance Gas: 4 x 91,000m³ VLGCs
 2020 - NIETO: 1 x 38,000m³ LGCs
 2020 - Byzantine Maritime: 4 x 38,000m³ LGCs
 2020 - Hartman: 5 x 5,000m³ LPG GCs
 2020 - INNO: 2 x 91,000m³ VLGCs
 2020 - Petredec Holdings: 6 x 93,000m³ VLGCs
 2020 - Trafigura: 6 x 84,000m³ VLGCs
 2020 - Union Maritime: 2 x 84,000m³ VLGCs
 2020 - BW LPG: 15 x VLGCs RETROFITS
 2020 - Trafigura: 6 x 84,000m³ VLGCs
 2021 - NYK Lines: 2 x 91,000m³ VLGCs

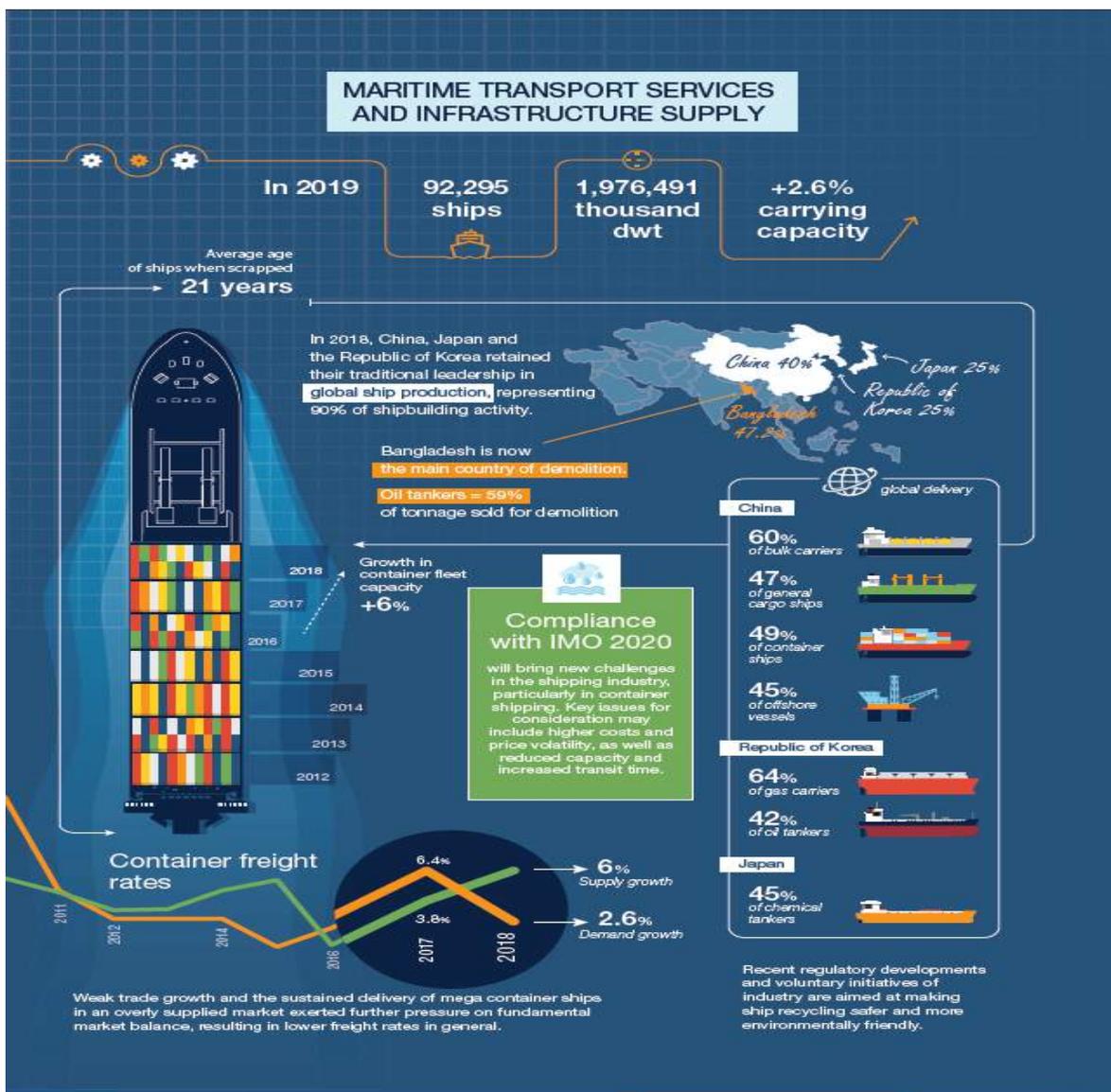
Currently LPG powers recreational and fishing boats mainly in USA, Chile and in smaller numbers in other countries like Italy, Germany, Spain, Ghana, Colombia, Turkey, Indonesia etc., most of them using converted engines.

Regarding large OEM engines ready to use LPG as a fuel, available today in the market are:

- ▶ MAN Diesel & Turbo Liquid ME-GIP, two stroke liquid gas injection engines.
- ▶ Wärtsilä 34G series, an Otto cycle, lean-burn, four-stroke engine, which is currently for stationary power plants but could be used also for marine.
- ▶ GE LM2500 gas turbine series.

In the market of smaller outboard engines, OEM models are available from:

- ▶ Mercury
- ▶ Propel
- ▶ Selva
- ▶ Tohatsu
- ▶ Yamaha



UNCTAD/RMT/2019/

Chapter Four

Roadmap

4.1 Market Outlook on Technology Developments

The next few years are bound to change a major part of the way that the shipping industry is operating, as there will be a tectonic shift in fuels used and as such, major conversion and retrofit projects on existing vessels, as well as planning for future-proofing current new buildings, are being set in motion by ship owners.

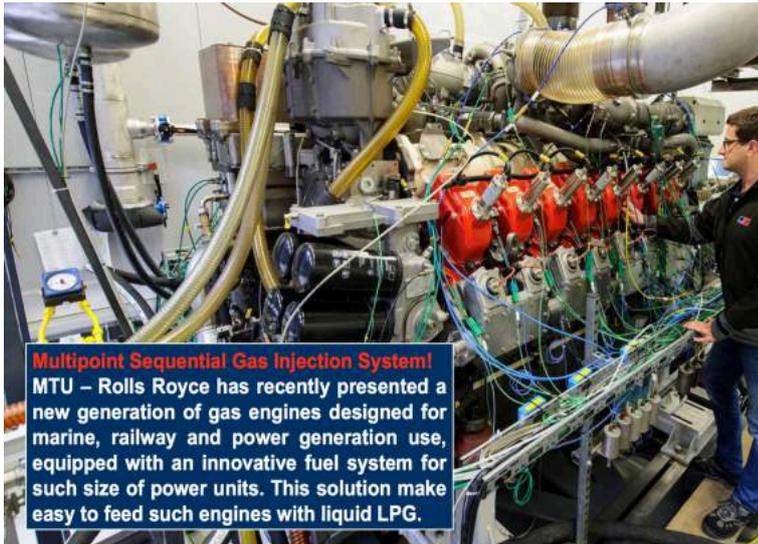


Image by X-Tech

The future of marine fuels appears to be a combination of fuel types combined with new propulsion technologies and possibly hybrid combinations. Given the environmental challenges facing the marine shipping industry to lower the exhaust emissions of SO_x, NO_x, PM, and CO₂, there will be changes in the mix of fuels that shippers use as they attempt to meet international and local exhaust emission requirements. **It will no longer be “one size fits all.”**

Possibilities ahead:

- ▶ Engines will continue to become cleaner and more efficient, following advancements of automotive and land industrial model counterparts.
- ▶ The use of steam turbines once favoured is no longer favoured for newly built due to the system complexity and low efficiency. Even the LNG sector is searching for new propulsion schemes to be installed to eliminate the need for the old-fashioned power plants. This leaves the competition playground wide-open to the diesel and gas turbines. Nobody can precisely decide which method is the best however, the gas turbines have more advantages, but the diesel engine is more reliable, and has good maintainability characteristics.
- ▶ Marine turbines use marine diesel oil as fuel, and in order to move a step closer to the future, new fuel resources must be chosen in efforts for the fuelling of marine turbines to have a clean and efficient shipping industry. LPG, NG and the hydrogen resources are the candidates for this operation.
- ▶ The move toward using LPG as a marine fuel will start to gain momentum as new environmental regulations are enacted and bunkering facilities are expanded. According to a recent forecast by MEC Intelligence, a market insight firm that focuses on the maritime sector, LNG-fuelled vessels amount to approximately 13% of the current newbuild order book and estimates for the rest 2021 and beyond show continuing growth in many classes of vessels triggering a huge growth in the market of alternative fuels. Prior to MEC’s forecast, classification society Det Norske had predicted that gaseous fuels would become the **dominant fuel source for all merchant ships within 40 years**. The reason for such growth is strict emission regulations requiring the reduction of sulphur oxides (SO_x) and nitrogen oxides (NO_x) to 0.1 percent in Emission Control Areas (ECAs) by 2015 and 0.5 percent globally by 2020. LPG/LNG, besides becoming cheaper.

- ▶ Other technologies are also being explored. These include the use of liquid hydrogen as a fuel to generate power within a combined fuel cell and battery system as well as solar panel and automated sail systems. At the same time, a new range of extremely efficient low-speed two-stroke diesel engines is being introduced as more operators take up slow steaming.
- ▶ Work with greener fuels such as LNG, LPG, solar & wind power and the stringent rigid norms about emission are expected to observe development for the global marine engine market. Four stroke engines are registering fast growth in the market, due to reliability, fewer emissions, smoothness, and quiet operation.
- ▶ When hybrids start appearing in the market, classic engine propulsion systems step back. In the car industry, the future seems to be hybrid and pure electric systems. Diesel-electric hybrid marine propulsion systems exist allow operation in “zero emission mode” for a limited time and under straight diesel power the rest of the time. A similar hybrid system had also appeared with the addition of solar collectors to complement charge the batteries. Hybrid power is very appealing involving the familiar internal combustion engine, which reduces also development costs, however, when it comes to marine, it should not be excluded that internal combustion engine may need to be abandoned entirely for something different, like the fuel cell driving electric motors, and perhaps in the future a fuel cell fuelled with LPG.

Fuel Technology and Compatibility

Different type of fuels can be used in different type of main machinery technology. LPG can match with both fuel cell and potentially with different types of gas engines, i.e. two-stroke dual-fuel engines (high pressure), four-stroke, pure gas, spark ignition engines (low pressure) and four-stroke, dual fuel engines (low pressure).

2 stroke slow speed	Dual fuel engine	4 stroke medium speed	Pure Gas Engines	Fuel cells	Hybrid Electric
<ul style="list-style-type: none"> •HFO •MDO/MGO •LSHFO •LPG 	<ul style="list-style-type: none"> •LNG •LSHFO •LPG 	<ul style="list-style-type: none"> •MDO/MGO •LPG 	<ul style="list-style-type: none"> •LNG •LPG 	<ul style="list-style-type: none"> •LNG •Hydrogen •Methanol •LPG 	<ul style="list-style-type: none"> •HFO •MDO/MGO •LSHFO •LPG

4.2 Market Outlook on Regions

Asia-Pacific: Most Lucrative Market

Asia-Pacific is the most lucrative marine LPG propulsion engine market, owing to an increase in shipbuilding industries in China & South Korea and growth in number of joint ventures with international brands. Moreover, rise in seaborne trade of crude oil mostly from Middle East countries to Asia-Pacific is another factor that drives the Asia-Pacific marine propulsion engine market and boosts the demand for marine engines. Due to the ship building activity in Asia Pacific region, countries such as China, Japan, and South Korea have become the largest marine engine market. An additional factor attributing to the growth would be the rise in maritime trade in South East Asia set up by China and other emerging economies in the region such as Indonesia. Countries such as Japan, China, and South Korea established more than 80% of ship building facilities.

In Europe and North America, the presence of many industries such as commercial vessels, offshore support vessels, and inland waterways vessels has boosted the demand for marine engines in these regions. Investments have increased in the marine engine market due to the existence of some of the world’s largest manufacturing sites of marine engines in North America and Europe regions. The new applications being considered on regular basis and clean fuel technologies being developed are rapidly changing in the U.S.A.

In the Middle East, the presence of several industries such as commercial vessels, offshore support vessels, and inland waterways vessels has boosted the demand for the marine engine in the region. As a result of government initiatives, regulation and policies, the Middle East marine engine market is expected to grow rapidly in the upcoming years.

4.3 Barriers to Growth

There are several specific barriers/drivers, which determine the size of the market opportunity. Key issues are highlighted below. The Recommendations Chapter proposes suggestions to overcome these barriers.

4.3.1 Customer economics: investment for ship owners and economics for fleet operators

Upfront cost is consistently raised as the single biggest barrier to market entry for new technologies. The cost of R&D to bring new technologies to maturity can often be prohibitive.

Cost is the primary decision factor for the majority of ship-owners, shipping companies and cargo owners. With strict budgetary pressures, many customers remain focused on immediate cost rather environmental factors, although in the large marine shipping sector, the IMO continuously increasing emissions reduction requirements are. **Having said that, it is worthwhile to note that the upfront installation costs of an LPG fuelled system compared to an LNG equivalent one is significantly lower.**

Type	Size (tons)	Engines	Engine Cost	Fuel System Cost	TOTAL CONVERSION COST
Tug	150	2 x 1,500 HP	\$1.2 million	\$6.0 million	\$7.2 million
Ferry	1,000	2 x 3,000 HP	\$1.8 million	\$9.0 million	\$10.8 million
Great Lakes Bulk Carrier	19,000	2 x 5,000 HP	\$4.0 million	\$20 million	\$24 million

Representative conversion costs to accommodate LNG can be as below, with the equivalent for conversion to LPG estimated at around 50% lower.

- ▶ Tug with 2 X 1,500 HP: about \$6 million.
- ▶ Ferry with 2 X 3,000 HP: roughly \$10 million.
- ▶ Bulk Carrier with 2 X 5,000 HP: about \$20 million.
- ▶ New construction incremental costs are projected to be somewhat less than conversion costs.

Cost Associated with Converting Marine Vessels to LNG Operation

Split incentives act as an impediment to the widespread adoption of LPG bunkering as in many cases, the fuel is paid by the charterer. It is the reduced fuel costs that pay the investment back. When these reduced fuel costs (operating costs) are not returned to the ship-owner, the investment will not directly be paid back.

LPG as a fuel would be most suited for newbuilding since the incremental investment costs are lower. Perhaps the single biggest challenge for the LPG sector to overcome is that associated with long-term future pricing. LPG prices tend to be quite volatile, with a significant element of 'seasonality' in year-round pricing associated with varying supply and demand profiles. Therefore, as discussed later in the report, an explicit recommendation of this study is to consider mechanisms which can be used in order to reduce the risk of future LPG price volatility, and thus improving the confidence of end-consumers of the fuel.

New Ship Construction Premium

The cost of building a new ship powered by natural gas has a premium over the construction cost of a conventional ship with fossil fuel. There is a cost increase for the gas engine and another for the gaseous fuel system and associated LNG storage tanks.

For example: A Germanischer Lloyd (GL) study in 2009 noted an additional investment of 25% over that of the cost for constructing a typical new container ship. According to a DNV report, if a ship spends more than 30% of its operating time in an ECA, the cost of gas-fuelled engines can be justified.

Increased Safety Requirements

The carriage of LPG as a fuel entails additional safety requirements over fossil fuels and results in construction features that are reflected in a higher construction cost. Safety-related costs include approvals (classification), and crew training and education.

Overall costs besides the initial acquisition cost or the cost of the fuel system modification depend largely on the relative price of LPG vs other fuels. In the case of dual fuel diesel LPG engines, the economics and cost benefits depend also on the amount of diesel fuel that is substituted across the full operational cycle of the engine as well as the world long term LPG supply.

4.3.2 Positioning LPG to policymakers and decision makers: Need to be on a level playing field with other alternative fuels

Policy makers such as legislators and governments at local, regional, national and EU level need to show clear support for LPG. Without the support from politicians at all levels, it will be difficult to set up the necessary infrastructure. The policies promoting alternative fuels must be long-term in vision, and the supporting legislation should be harmonised and implemented fairly and consistently across countries and different types of technology. In the early stages of implementation, some form of public financial funding or incentive schemes will be probably being required to support the initial investments in LPG vessels and If LPG marine engines are to reach potential market they need to be recognised and given fair treatment to other technologies e.g. based on their primary energy efficiencies carbon saving potential. This is an on-going process in many regions. Regulations and incentives need to be finalised for inclusion of LPG in marine engines. These regulations need to take into account the use of LPG as a fuel.

On the other hand, for policy makers to take a standpoint and make important decisions, they will need credible and unbiased information on LPG as a potential clean marine fuel, addressing both the risks and benefits regarding health, safety and environment. Input to the process must be of high quality to support policy making decisions. The political decision makers must have a realistic view of the technical and financial challenges posed by LPG and possible implications for the other stakeholders.

As the market for marine engines is global, international regulations apply. International standards or regulations are also important to help ensure that these systems are safe, reliable and in compliance with emissions regulations. There is a lack of safety regulations for ship-to-ship transfer and for bunkering while passengers are on board.

4.3.3 Technology Development of new engines: In the recreational sector, there is a slow rate with limited growth. In big vessels, there are few early development projects under development

At present, there is a lack of marine LPG engines. The development of engines with other competitive fuels and technologies has largely overpassed those with LPG. A significant part of the market potential for LPG marine engines is currently based on the expected technology developments, which will widen applicability. If this does not happen as expected the market potential will be very limited and growth may even stop altogether. Major manufacturers are hesitant in developing LPG versions of their models. This is probably the most important hurdle today. R&D investment is absolutely key.

4.3.4 Commercialisation of new engines: Sales, servicing and maintenance networks are required

For new engines, partnerships need to be developed or acquired through partnerships with bigger companies.

4.3.5 LPG Awareness/Perception for decision makers: Shared Vision with LPG marine engines, Equipment and Engine manufacturers, Naval Architects, Ship owners, Ship operators and All Types of Users as a Preferred Option

Raising awareness of the existence of marine engines, possible applications and their market potential is the first major challenge. Communications initiatives are needed in order to expand LPG's position as an important alternative fuel and to increase sales.

4.3.6 Bunkering Infrastructure: Development of bunkering infrastructure uncertainty of LPG supply and bunker price makes it difficult for a ship-owner to invest on LPG-fuelled ship

For LPG to become an attractive fuel for the majority of ships, a global network of LPG bunkering terminals must be established or LPG-fuelled ships will be limited to coastal trades where an LPG bunkering network already exists. The situation is sometimes described as a "chicken-and-egg" dilemma. Until the bunkering infrastructure is in place, ship owners may not commit to LPG fuelled ships and vice-versa. For short sea shipping, the filling stations on key ports are lacking. It should be investigated the possibility of movable tanks to be trucked on board a barge or a LCM (landing craft) and used for refuelling ships.

What remains as the biggest hurdle for the establishment of an LPG bunkering market is the uncertainty regarding the actual LPG bunkering price and the relative price compared to the other bunkering fuels. Will the relative LPG price be sufficiently low for ship owners to have a positive business case when investing in an LPG-fuelled ship and thus generating LPG demand and will it be sufficiently high for the bunkering fuel supplier to have a positive business case.

Small scale shipping is facing severe barriers on its way to LPG

- ▶ High equipment costs due to high safety requirements, currently small target market, limited development activities & high component prices.
- ▶ Limited range of available engines.
- ▶ Lack of small-scale bunkering facilities.
- ▶ Missing harmonisation of LPG-coupling and transfer equipment (link between delivering facility and receiving vessel).
- ▶ Rules and regulations (e.g. IGF code) for vessels and legal framework for LPG bunkering infrastructure not finalised yet long and expensive permitting processes.
- ▶ Education and Training of LPG handling crew.

Other constraints

Terminal operators

- ▶ The terminal operators are independent companies building and operating the LPG terminal on the port premises, where the LPG will be stored and distributed to different customers. If this step is not managed by the port or the gas supplier, the LPG infrastructure demands the support of a competent terminal operator who can establish and

run the terminal and offer a realistic contract model for gas suppliers regarding quantities and contract length (short-term versus long-term).

- ▶ Terminal operators will require sufficient user demand with the potential economies of scale offered by different types of gas users such as the energy sector, manufacturing industries, shipping, and land transportation (car, trucks, and so on.). Moreover, the regulatory framework should be in place, and external funding may also be necessary to persuade potential operators to commit to investing in a new terminal.

Ports

The ports are a crucial part of the LPG supply chain. From a sustainable LPG infrastructure perspective, enough ports must make locations available for small-scale LPG terminals and bunker facilities. The port authority needs to establish local regulations and port by-laws, approved by other relevant authorities. In addition, the ports may be a possible source of funding for investment support.

4.4 Market Potential

Several high-level market characteristics are identified which create a strong potential for LPG Marine Engines.

<p>Offshore Renewable trends</p>	<p>Offshore renewable energy is a major greening trend. This estimate is based on the number of ships required for constructing and operating the planned parks, including installation vessels, cable layers, support vessels (maintenance, crew accommodation and crew transfer), and repair vessels, as well as the manufacturing of foundations (jackets), platforms and other components. Given that such initiatives are also being undertaken in Asia and North America, the scale of market potential could increase further.</p>
<p>The regulatory drive towards CO₂ abatement initiatives in the light of 2020 regulations</p>	<p>A large percentage of the current fleet is quite old and may not comply with the strictest environmental rules; therefore, retrofit opportunities might arise from green regulatory drivers. Existing ships that do not have dual tanks may have to be retrofitted with dual fuel systems, so they can perform fuel switching when they enter an ECA.</p>
<p>Attractive LPG price</p>	<p>The decline in oil prices and the corresponding decline in propane prices in 2014 and 2015 provides a window of opportunity for fleet operators</p>
<p>Global Trade and industrial market growth</p>	<p>Commercial and industrial markets are growing following increased LNG and Shale gas production mainly in the USA. The US exports and the growing worldwide supply (Australia/East Africa) as well as development of new markets create opportunities for LPG vessels built, which could use LPG as propulsion fuel.</p>
<p>Adequate supply of LPG product</p>	<p>The global LPG fundamentals in 2017 are shaping up to be bullish. U.S.A. LPG output from natural gas processing plants more than doubled between 2010 and 2017 due to the shale boom. With domestic demand effectively static, the surplus is largely destined for overseas markets, and bunkering. Iraq confirmed the increase in LPG production. Based on our projections for supply and demand for the balance of the coming years we expect the market to continue to move to surplus.</p>
<p>Increasing awareness of the advantages of new technologies</p>	<p>The most important aspect of market transition from the entry stage to the early stage is the growth of confidence in the new technology among all key stakeholders—LPG users, companies, naval architects, investors, policy makers and Government. Due to rapid growth of LNG technology many stakeholders have created opportunities for the quicker and easier adoption of LPG.</p>
<p>Increasing number of new ship orders complying with regulatory developments for marine emissions</p>	<p>All new ships are expected to follow a trend towards higher fuel efficiency, partly driven by the increasing fuel prices but also by regulatory measures (EEDI is seen as a minimum level). Two main areas of market potential are fuel efficient systems and alternative fuel-based solutions. For newbuilding, the market potential can be considered large. An accelerated replacement of vessels, driven by fuel efficiency, as is observed in some market segments (viz. containerships), may occur. However, this is difficult to quantify, given that at the same time this is hampered by the relatively young age of the existing world fleet.</p>

4.4.1 Target Regions

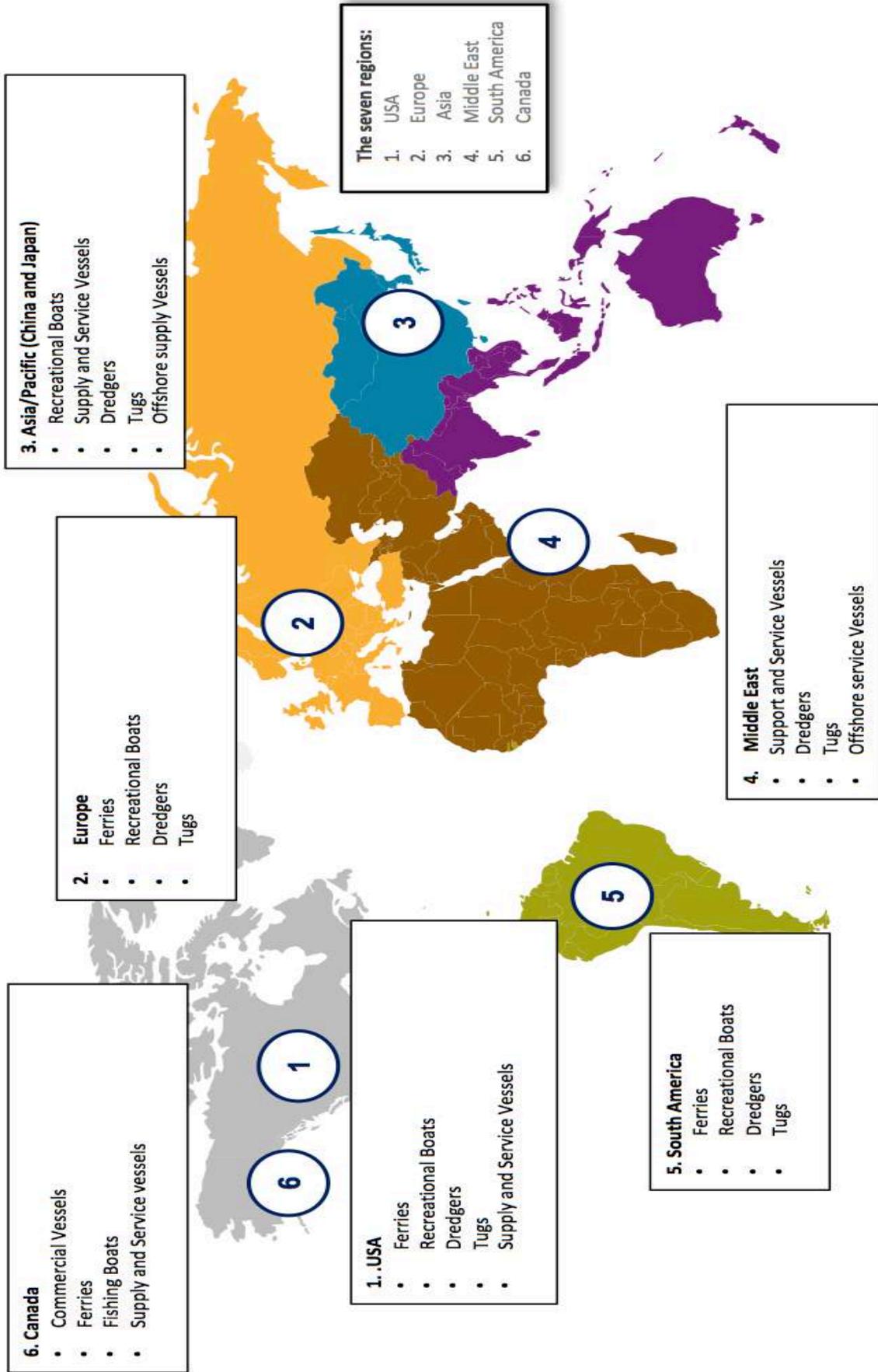
LPG is expected to witness significant growth in the near future owing to increasing alternative fuels demand mainly in the shipping sector to minimise environmental concerns such as carbon emission levels and pollution levels. In addition, it is one of the cheapest energy sources, which makes it more suitable than diesel and gasoline in the global transportation industry.

Based on the analysis of the market characteristics across major region, the figure below identifies core regions where LPG marine fuel could be targeted.

Type of Vessel	Regions						
	USA	South America	Europe	Middle East	Asia	Canada	Rest of the world
Commercial Vessels	XX	XX	XXX	X	XX	XXX	X
Cruise Vessels	XX	XX	XXX	X	XX	XX	X
Ferries	XXX	XXX	XXX	X	X	XX	XX
Recreational boats	XXX	XXX	XXX	XX	XXX	XXX	XXX
Fishing Boats	XX	XX	XXX	X	X	XXX	X
Supply and Service Boat	XXX	XX	XX	XXX	XXX	XXX	X
Dredgers	XXX	XXX	XXX	XXX	XXX	XX	X
Tugs	XXX	XXX	XXX	XXX	XXX	X	X
Naval	X	X	X	X	X	X	X
Offshore service	XX	XX	XXX	XXX	XXX	X	X

XXX= High priority, XX = Medium priority, X = Low priority

This figure provides analysis of market potential for marine fuel in each region based on type of ships/boats.



4.4.2 Target Boat/Ship Segments

As the shipping industry considers alternatives to HFO, part of the market will shift toward MGO, part toward LNG and LPG and some possibly to liquid biofuels.

- ▶ Marine vessels equipped with scrubbers will retain the advantage of using lower-priced HFO.
- ▶ Shipping that takes place outside ECA areas might choose.
- ▶ HFO or LSFO depending on future global regulations.
- ▶ Ships operating partly in ECA areas will probably choose MGO as a compliance fuel.

Heavy shipping within ECA areas, however, might require a complete shift to LPG

The choice of fuel lies primarily with the charterer (the shipping agent) who, in principle, rents the vessel from a ship owner. Depending on the engine type, the charterer then has a choice of fuels. Typically, high-sulphur residual fuels or low-sulphur distillates are among the choices. Depending on the abatement technologies installed by the ship owner and the requirements set by the authorities in the specific region of operation, the charterer then selects and acquires the fuel.

The choice of fuel for large freight vessels is basically on the charterer, who also must select a vessel for each transport. The choice of fuel is then affected by many factors, such as emissions requirements on the selected route, the fuels' availability and price, and the abatement equipment installed on the ship. The contract duration will influence the owner's decision on whether to retrofit abatement equipment.

Other segments (groups of customers) are private boats, fishing boats, ferries, etc. that will have a shift to LPG

In terms of global fuel use, however, freight vessels are dominant

LPG fuel is most suitable for the following ship types:

- ▶ Ships & boats with a set route and short range (4,000 nm or less) – storage tank capacity is not overly large & fixed bunkering port can be established (Ferries, Coastal ships & tugs).
- ▶ Ships that operate mostly within an ECA – low emissions are required.
- ▶ Ships without high fuel consumption rates – required storage capacity is practical and bunkering time & frequency is not high.
- ▶ Ships that trade where a source of LPG is available.
- ▶ Ships intended for cross ocean passages designed to use LNG in ECA only need a means to effectively utilize BOG when mid-ocean and heavy fuel is the primary fuel.

The processes and dynamics differ considerably by type of ship or equipment component.

- ▶ Passenger vessels (both cruise and ferry ships will be addressed) .
- ▶ Dredgers.
- ▶ Recreational boats.

These three segments are considered of high priority because of their importance for the EU and proximity within ports and ECAs.

Based on the current situation of LPG-fuelled ships, a **SWOT analysis** is used to map internal and external influence factors with no hierarchical structure that reveal the development potential of this market.

<p>Strengths</p> <ul style="list-style-type: none"> • Full compliance with current and future SOx emission requirements, including ECA and CECA areas • Reduction of all other pollutant emission • Environmental excellence • Operational efficiencies • Cleaner engines, cheaper maintenance • Adaptability to major vessel engines • Easy storage, faster refuelling • Wide availability of bunker ships and facilities • Economic efficiencies-Low OPEX and CAPEX cost • Savings from reduced fuel consumption • More efficient engines and cheaper to maintain • Abundant LPG reserves worldwide 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Variety in Engines Availability • Currently fossil fuel derived • Increase in volume of fuel tank
<p>Opportunities</p> <ul style="list-style-type: none"> • Government supporting policy • Strict emission restriction • National strategies of optimising energy structure • Support from state-level research projects 	<p>Threats</p> <ul style="list-style-type: none"> • No infrastructure for LPG-fuelled ships • Lack of standards and regulations • Lack of Class rules and notations

Chapter Five

Recommendations

The Roadmap section above identified the critical barriers to market uptake for marine engines with LPG. In this section, recommendations on how each of these barriers can be overcome are presented, and which type of market actors have a role to play.

The summary table below indicates the varying roles of each type of stakeholder in overcoming the barriers to market growth. Each barrier is explained in detail in the text after the table.

Roles are differentiated between “Lead Role” (the actor(s) is critical in overcoming the barrier), and the “Support Role” (the actor(s) can support but is not the critical element in overcoming the barrier).

Key: XX = Lead Role; X = Support Role.

Barrier	Market Actor				
	Industry Associations	LPG Distributors, Suppliers	Engine Manufacturers Naval Architects Shipbuilders	Shipping, Bunkering Industry	Government
Customer economics	X	XX	XX		XX
Positioning LPG to policymakers and decision makers	XX	X	X	X	XX
Technology development of new engines	X	X	XX	X	X
Commercialisation/getting products to market	X	X	XX		X
LPG Awareness/perception	XX	X	X	X	X
Bunkering Infrastructure	X	XX	X	X	X

5.1. Customer Economics- investment for ship owners and economics for fleet operators the Greatest Challenge

- ▶ **Providing subsidisation** could bring down the upfront cost. ROLE OF GOVERNMENT.
- ▶ **Lobbying to ensure that LPG as engine fuel in marine industry receives a fair incentive rate** to be on a level playing field with other competing technologies such as diesel, CNG, LNG, will ensure that an LPG engine is considered as a preferable option. ROLE FOR INDUSTRY ASSOCIATION.
- ▶ **Manufacturers of engines, equipment**, to integrate LPG options from the beginning with the naval architects to avoid subsequent modifications and added costs. ROLE FOR MANUFACTURERS, NAVAL ARCHITECTS.
- ▶ **Price indexing and the wider use of long-term LPG contracts can be used to help mitigate the risk of wide LPG price fluctuations, and its associated unpredictability.** This would give existing and new customers greater confidence in future fuel prices of the fuel and therefore in the future commercial viability of their operations. The

use of longer-term contracts is more common in LNG markets than in LPG. LPG is more exposed to, for example, seasonal changes and short-term shifts in the supply-demand balance. In addition, while diesel prices are generally higher than those of LPG currently, the volatility can often mask this feature in the eyes of end users. ROLE OF LPG DISTRIBUTORS, SUPPLIERS.

- ▶ **Engine manufacturers** will create cost-reduction potential by lowering upfront costs, improving system efficiencies (engines, powertrains), with running cost benefits. ROLE FOR ENGINE MANUFACTURERS.
- ▶ **Providing incentives** will bring down either upfront costs or running costs. ROLE OF GOVERNMENT.

5.2. Positioning LPG to policymakers and decision makers: Need to be on a level playing field with other alternative fuels

- ▶ **Lobbying** to ensure that LPG powered engines in single or dual LPG/diesel mode are included in regulatory framework and incentive schemes. This should cover the whole marine operation chain. Primary role for the associations and LPG companies to make policy-makers aware of the benefits of LPG, their safety and the potential of this technology. ROLE FOR ASSOCIATIONS.
- ▶ **Contacting** various societies such as International Association of Classification Societies (IACS), Society of International Gas Tanker and Terminal Operators (SIGTTO) and Society for Gas as Marine Fuel (SGMF) to promote the use of LPG as marine fuel. ROLE FOR ASSOCIATIONS.
- ▶ **Lobbying** to ensure worldwide standards and certification regulations for OEMs and retrofit technologies. Associations, LPG companies and manufacturers must ensure that policy-makers and regulators develop safe, reliable regulations and in compliance with new emissions requirements. ROLE FOR ASSOCIATIONS.
- ▶ **Position** LPG as a fuel in the marine industry will be a complex and long-term challenge to tackle effectively, with multiple facets to it. LPG industry should develop and communicate a detailed vision of the role of LPG in marine fuel's future. ROLE OF ASSOCIATIONS.
- ▶ **Developing** safety measures to allow bunkering while passengers on board. ROLE OF ASSOCIATIONS.
- ▶ **Supporting** efforts to develop revised regulations. ROLE OF ASSOCIATIONS.
- ▶ **Support** shipyards to encourage vessel conversions to LPG fuelled and LPG fuelled new builds. This could help countries to develop a sustainable niche in the global shipbuilding sector. ROLE OF GOVERNMENT.

5.3. Technology Development of new engines and ship designs: Big vessels - few early projects under development. Recreational sector - slow rate with limited growth.

- ▶ **Investment in R&D** to support and accelerate the development of LPG fuel technology in Marine Engines and maximise its potential vessel types. This is probably the most important enabler at present since development on other competitive fuels and technologies has largely overpassed those of LPG resulting in a serious lack of LPG engines. If this does not change rapidly, enormous opportunities will be lost. This could include investments to adapt existing LNG fuelled engines to run on LPG. Besides investment, a long-term vision of what the market requires is needed. Primary role for engine manufacturers but also largely for LPG distributors. There could be a role also for policy makers by making R&D funding available to develop new product concepts suited to their markets. ROLE FOR MANUFACTURERS (to develop), LPG DISTRIBUTORS, POLICY MAKERS (to assist with funds), ASSOCIATIONS (to facilitate).
- ▶ **Market analysis** to identify which markets, market sectors and applications have most potential, types of marine engines needed and what R&D developments should be made to ensure that the technology is well-suited to future needs and trends. ROLE FOR MANUFACTURERS, LPG DISTRIBUTORS AND ASSOCIATIONS.
- ▶ **Fuel quality** to be harmonised to serve as basis for engine and technologies development and reliable and consistent engine performance. LPG companies to ensure consistent delivery of good quality fuels. ROLE FOR LPG DISTRIBUTORS, SUPPLIERS.

-
- ▶ **New design and technical development** more demanding footprint on-board of vessels takes up commercial space. Pursue new designs of tanks and powertrain installations; reconsideration of safety measures. ROLE OF NAVAL ARCHITECTS, SHIPBUILDERS.
 - ▶ **Developing international standards** for marine engines and waterborne vessels to be shared across the marine industry. ROLE FOR ASSOCIATIONS/ GOVERNMENT.
 - ▶ **Lobbying to support the emissions requirements/technologies and to ensure legal compliance.** ROLE FOR ASSOCIATIONS.

5.4. Commercialisation & Getting Products to Market

- ▶ **Support with developing partnerships** for designing new engines and powertrain systems. Role of the associations to put main stakeholders in the ship building value chain in touch with partners to develop partnerships. ROLE FOR LPG DISTRIBUTORS AND ASSOCIATIONS.
- ▶ **Expanding offerings** to include LPG marine engines via existing design channels ROLE FOR MANUFACTURERS AND ASSOCIATIONS.
- ▶ **Market research** to identify which market segments to target and what drives and motivates those customers in their decision-making process in deciding the type of fuel and engine to be used. ROLE FOR ASSOCIATIONS, LPG DISTRIBUTORS and MANUFACTURERS.

5.5. LPG awareness for decision makers: Shared vision with marine engine manufacturers, naval Architects, designers, ship owners, ship operators and traders need to be considered

- ▶ **Stakeholders need to continue to collaborate** and use the findings of this project to support current and proposed marine LPG initiatives. There are major potential environmental and economic benefits to be realised if LPG is adopted as a marine fuel. ROLE OF ALL STAKEHOLDERS.
- ▶ **Developing a consistent vision** for marine engines to be shared across the industry, with end goals and interim steps. The goals could be to target marine engine developers and reach specified market penetrations for marine vessels. ROLE FOR ASSOCIATIONS and LPG DISTRIBUTORS.
- ▶ **Marketing/awareness-raising activities** involving for example information dissemination demonstrating real technology performance, applicability and potential, targeted marketing events for ship-owners and operators, engine manufacturers, information/training events, sector exhibitions, etc. ROLE FOR ALL MARKET ACTORS: ASSOCIATIONS, LPG DISTRIBUTORS.
- ▶ **Collection of market data** of LPG marine engines emission data to demonstrate the contribution LPG engines are making to carbon saving targets etc., to be targeted at governments. ROLE FOR ASSOCIATIONS and LPG DISTRIBUTORS.
- ▶ **Publishing** information documents and materials (brochures, charters of benefits etc.) with all types of related information, including safety, easily accessible to the stakeholders to increase understanding and address potential concerns related to LPG.

5.6. Bunkering Infrastructure: Development of bunkering infrastructure, uncertainty of LPG supply and bunker price, a concern for a ship-owner to invest on LPG-fuelled ship

- ▶ **Expand bunkering network** to develop extensive bunkering infrastructure and dedicated vessel refuelling facilities. For short sea shipping, the filling facilities in key ports are lacking. ROLE OF LPG DISTRIBUTORS.
- ▶ **Provide incentives and funding support** for pilot projects, technology developments, etc. ROLE OF GOVERNMENT.

- ▶ Consider underutilised LPG carriers to be brought to use to function as bunkering stations. Ship to ship loading of LPG is a realistic prospect for bunkering LPG from an LPG carrier. ROLE OF SHIPPING/BUNKERING INDUSTRY, LPG DISTRIBUTORS.

Appendices

Appendix 1

Hybrid Propulsion Packages

Offshore fishing vessel (78m):

- 1 x 6L32/44CR: 3600 kW
- 1 x CPP VBS 1020: 5300 kW, Ø 4,2m with AHT nozzle and rudder bulb
- 1 x Shaft machine for PTO/PTI/PTH operation
- 2 x 9L16/24 + 1 x 6L16/24 aux. gensets:
2 x 941 kW_e + 1 x 627 kW_e



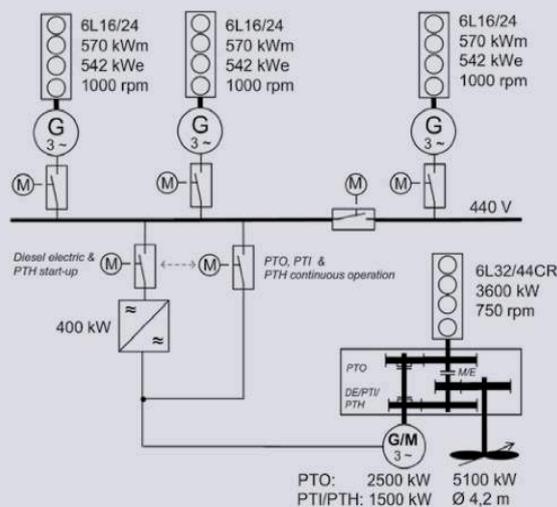
Operation modes:

1. *Diesel-mechanic propulsion:* M/E and propeller are operated in combinator mode. SG breakers are open. Gensets supply power for the vessel's consumers.
2. *Diesel-mechanic propulsion with PTO:* M/E is running and PTO is engaged. The gensets are stopped. Constant speed mode and combinator mode are available, delivering a constant net frequency or a variable net frequency in a range of 50 to 60 Hz.
3. *Diesel-mechanical propulsion with boost:* Both M/E and gensets are running at constant speed. The shaft

machine is operated as a PTI-motor which is boosting the propeller.

4. *Diesel-electric propulsion (PTH):* M/E is stopped. Gensets are running. The propeller can operate either with constant speed or with variable speed. In constant mode the PTH-motor is directly connected to the gensets. In variable speed mode the PTH-motor is connected via a frequency converter, which is also used as starting device for the PTH-motor and for slow speed and sailing in Diesel-electric mode.

Single line diagram

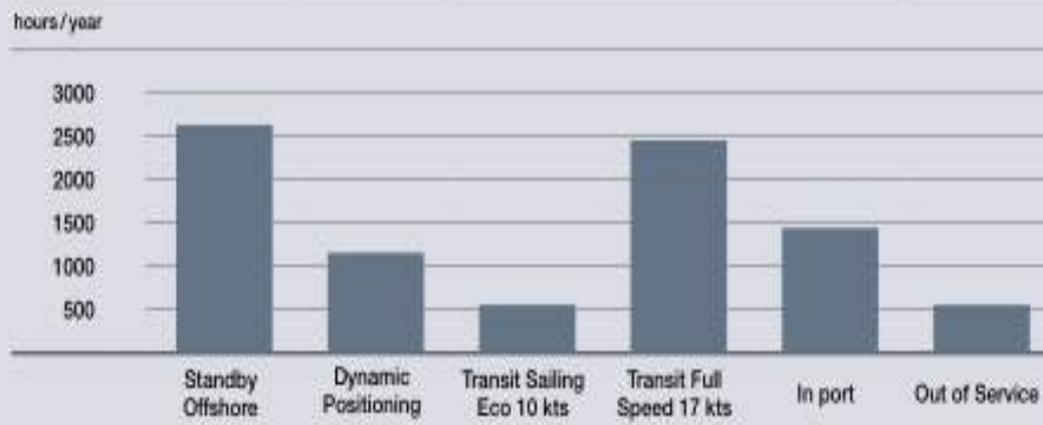


Multi purpose supply vessel (95m):

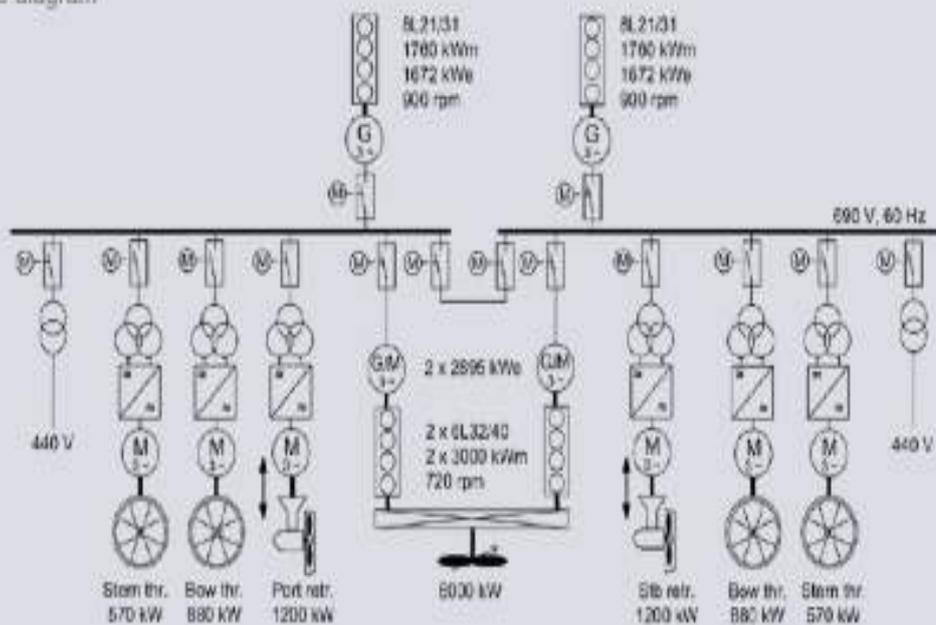
- 2 x 6L32/40: 2 x 3000 kW
- 2 x 8L21/31: 2 x 1760 kW
- 1 x CPP 6000 kW
- 2 x Shaft machines for PTO/PTI operation



Operational profile



Single line diagram





LPG as Fuel: Techno-economic study

Life Cycle Cost Analysis (LCCA)

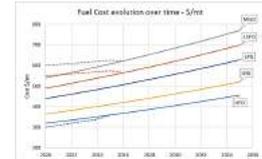
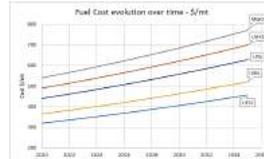
8 | LPG as fuel: Techno-economic study

Assumptions

- System Life expectancy 20 years
- Initial Fuel Cost 2020 (2.4% annual increase)
- HFO: \$320/mt, LSFO: \$490/mt, MGO: \$540/mt.
- LPG as fuel: 440 \$/mt equivalent to 1 mt MGO

Temporary Increase of LSFO-HFO differential

Fuel Differential	HFO	LSFO	MGO
2020	300\$/ton	500\$/ton	550\$/ton
2021	315\$/ton	515\$/ton	565\$/ton
2022	330\$/ton	530\$/ton	580\$/ton
2023	\$345\$/ton	545\$/ton	595\$/ton
2024	355\$/ton	560\$/ton	610\$/ton
2025	360\$/ton	575\$/ton	625\$/ton



10 | LPG as fuel: Techno-economic study



Assumptions (Cont'd)

Main Engine	Seagoing	Maneuvering	Port/Anchorage
Number Operating	1	1	0
Load (%)	75% - 90%	10% - 30%	0
Annual Running Hours	6,720	240	0

Auxiliary Engine	Seagoing	Maneuvering	Port/Anchorage
Number Operating	1	2	2**
Load (%)	35% - 55%	35% - 50%	75%**
Annual Running Hours	6,720	240*	6,037**

Auxiliary Boiler	Seagoing	Maneuvering	Port/Anchorage
Number Operating	0	1	1
Load (%)	-	-	-
Annual Running Hours	0	240	763*

Fuel Consumption	M/E	A/E	A/B
Seagoing	1.90 mth	0.15 mth	0 mth
Maneuvering	0.63 mth	0.31 mth	0.23 mth
Port/Anchorage	0 mth	0.46 mth	0.23 mth

- 27% of time per year in ECA zones
- As advised by M/E makers 10% gain in consumption in gas mode. Based on this, and \$440/t LPG, annual saving \$590,000

* Total hours for 2 A/E running
 ** Total of Port and Other (load-discharge-cooling of cargo). 1/3 of time with 3 A/E has been added in hours to the 2 A/E

* Total of port and other (load-discharge cooling of cargo)

10 | LPG as fuel: Techno-economic study

LCCA Results

- Simple Payback Period:

SPP	M/E Only
Compliant Fuel vs LPG	2.73 years

- Discounted Payback Period:

LPG	Discounted Payback Period
M/E Only	2.8



11 | LPG as fuel: Techno-economic study



LCCA Results (Cont.)

- Life Cycle Cost Analysis indexes

LPG	M/E Only
ROI (% per year)	33.40
NS	\$28,028,929
SIR	7.0
AIRR	33.40

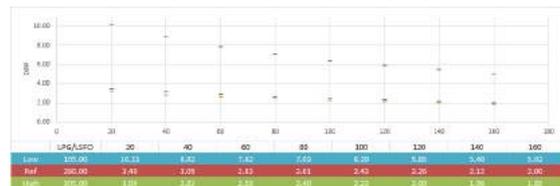
- ROI (Return On Investment - % per year);
 $(\text{Annual Profit} \times 100) / \text{Capital Investment}$
- NS (Net Savings);
 NS is a current value expressing the net lifecycle benefit after costs are subtracted
- SIR (Savings to Investment Ratio)
 $\text{Present Value of Operational Saving} / \text{Present Value of Additional Investment Cost over the life of the investment}$
- AI RR (Adjusted Internal Rate of Returns);
 $((1+r)^N \cdot (\text{SIR})^{1/N}) - 1$ with r the rate of reinvestment and N the number of anticipated lifetime of the investment (15 years in this case). A measure of annual percentage yield from an investment

12 | LPG as fuel: Techno-economic study



Sensitivity to No. of Days at Sea

- Effect on discounted payback period from varying the LSFO-LPG differential and the annual days at sea from 105 to 305, for the LPG conversion



13 | LPG as fuel: Techno-economic study



Abbreviations

BOG	“Boil-Off” Gas
CO ₂	Carbon Dioxide
CODAG	Combined Diesel and Gas
COGES	Combined Gas and Steam
DFDE	Dual Fuel Diesel Electric
DNV	Der Norske Veritas
ECA	Emission Control Area
EEDI	Energy Efficiency, Design Index
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
IACS	International Association of Classification Societies
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
LSHFO	Light Sulphur Heavy Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MFO	Marine Fuel Oil
MGO	Marine Gas Oil
NG	Natural Gas
NO _x	Nitrogen Oxides
PM	Particulate Matter
PWC	Personal watercrafts
ROI	Return on Investment
SCR	Selective Catalytic Reduction
SGMF	Society for Gas as Marine Fuel
SIGTTO	Society of International Gas Tanker and Terminal Operators
SO ₂	Sulphur Dioxide

Copyright

© 2021 World LPG Association.

All rights reserved. Neither this publication nor any part of it may be reproduced, stored in any retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

All information in this report is verified to the best of the authors' and publisher's ability. However, the accuracy of the data contained in the report cannot be guaranteed, and no responsibility can be accepted for any consequence of their use.





182 avenue Charles de Gaulle, 92200 Neuilly-sur-Seine, France
Tel: +33 1 78 99 13 30
association@wlpga.org
www.wlpga.org
 @ExceptionalNRG

