Guide to
LPG Use in Waterborne Vessels

GOOD INDUSTRY PRACTICES

WLPGA

The World LPG Association

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

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

Acknowledgements

The World LPG Association (WLPGA) would like to thank Captain Bernardo Herzer, Chairman and Founder of LEHR www.lehrmarine.com, for his valuable contribution to this document. In particular, his permission to use several photographs that appear in the document and the case study described in Chapter Eleven which originated from Captain Bernardo.

Captain Bernardo is also the Chairman of the WLPGA Marine Working Group which has approved the final draft.

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Chapter One

Background

The WLPGA is committed to providing independent advice to Liquefied Petroleum Gas (LPG) stakeholders to ensure, above all, safety in the operation of LPG equipment and the business generally.

The two WLPGA guidelines - *Good Business Practices* and *Good Safety Practices* - have been used extensively over the years all over the world to provide guidance across all areas of the LPG industry. Since their original publication in English, they have been translated into several other languages.

These two guidelines have been designed to provide general advice to all stakeholders on best practices throughout the supply and distribution chain.

Following the success of these guidelines it was decided to develop and publish more detailed advice in certain areas of the supply and distribution chain that are considered more critical and where more prescriptive advice would be helpful.

Several more prescriptive guides have been published covering subjects such as *LPG Cylinder Management, LPG Bulk Storage, LPG Bulk Road Tanker Management* and *LPG Use in Commercial Kitchens.*

It was decided to address an application where LPG offers great benefits but where its use has been to date quite limited.

This guide focuses on the use of *LPG in water borne vessels*. The use of LPG in boats and ships 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 such as marine gas oil, and marine fuel oil.

- **90% of the world's goods are carried by sea**
- **CO_2 emissions from shipping are double those of aviation**
- **Maritime CO_2 emissions could rise by 75% in the next 15 to 20 years**
- **Sulphur level in marine fuel oil being reduced from 3.5% to 0.5% by 2020 [International Maritime Organisation (IMO) Oct 2016]**
- **CO_2 monitoring for all ships to establish a base line for future reduction**
- **EU leading the way but a global system is under negotiation within the IMO**
- **Large ships using EU ports will from 2018 be required to report verified annual emissions**
- **Pressure on marine fuels provides opportunities for gas to displace them**
- **This Guide sets out some of the issues and opportunities for LPG**

This has opened an opportunity for LPG but because of the nature of the product it was felt there was a need for this guide which addresses some of the concerns of using LPG in vessels on the water.

The target audience for this document are the LPG stakeholders who have an interest in the choice of fuel for water borne vessels.

The main objectives of this guide are threefold:

(I) Firstly, to provide a toolbox of information, data and compelling arguments in support of using LPG as the fuel of choice in water borne vessels. The target for this will be vessel owners and other stakeholders who decide on the type of fuel used in vessels, as well as local and national authorities that drive legislation impacting on the choice of fuel for water borne vessels.

(II) Secondly, to explain the practical issues of safely sourcing, storing, handling, distributing and using LPG in these applications using case studies and practical illustrations. This information will be useful for operational staff who have the responsibility of establishing supply and distribution facilities to ensure LPG reaches those applications safely.

(III) Lastly the guide will discuss the opportunities for using LPG in water borne vessels, from small recreational boats to large ocean going tankers, and consider the challenges that might be faced. It is hoped to secure endorsement for this Guide as a tool for change from leading stakeholders such as boat manufacturers, ship owners and the IMO.

This document has been drafted by a small working group consisting of senior representatives of existing LPG business from around the world together with experts in the maritime business.

Chapter Two

Executive Summary

The clean handling and efficient burning properties of LPG make it an ideal engine fuel for waterborne vessels.

The consequences of a major diesel or marine fuel spillage can be disastrous for marine life and the environment. Even small leaks from recreational craft can be a nuisance and cause embarrassment.

LPG is a colourless vapour and if a leak occurs it readily disperses, leaving no residue. A key issue that needs attention is the fact that LPG vapour is heavier than air and so any leak may either remain in the vessel or disperse on water. This needs to be tackled with good fuel system design.

- **LPG is a proven engine fuel with excellent clean handling properties & low emissions**
- **LPG has good properties as a marine fuel for all vessels**
- **LPG vapour is heavier than air creating a challenge for use in vessels**
- **Fuel storage and distribution system needs to vent any leaks out of vessel**
- **Sea water borne vessels present corrosion challenges to the fuel system**
- **LPG is already being successfully used in some vessels**
- **Opportunities exist for LPG to be used in all types of water borne craft**
- **There is increasing pressure on emissions from large water borne vessels**
- **Traditional bunker fuels create environmental risks if spilled**
- **If large LPG tankers used the cargo as fuel they would save time bunkering**
- **There is a need for education and training of all personnel involved**

LPG is a very good engine fuel and has been successfully used as a transport fuel for both on and off road vehicles for over fifty years. It is today the world's most popular alternative to gasoline (petrol) and diesel with over 26 million vehicles running on LPG.

LPG's clean burning characteristics make it a popular alternative to gasoline and diesel where airborne pollution is a concern.

There is an increasing focus on diesel emissions by governments, following the World Health Organization (WHO) announcement in July 2012 confirming that diesel emissions were a Group One carcinogen to humans.

This was followed in 2015 by the Volkswagen (VW) diesel emissions scandal where 'real world' exhaust emissions were found to be many times worse than results claimed under unrealistic test bed conditions.

With the onshore industry responding to environmental challenges, emissions from water borne vessels are becoming a proportionately greater part of the total global emissions.

Diesel emissions are under scrutiny in all applications including diesel powered trains (photo courtesy of www.lpgas.com.au)

It is estimated that emissions from ships account for between 2-4% of global CO_2 emissions, 10-20% of global NOx emissions and 4-8% of global SO_2 emissions (Einang 2007).

LPG emissions are significantly lower compared to diesel, gasoline (especially two stroke mix), middle distillate oil (MDO), marine gas oil and heavy marine fuel oil (HMFO).

With more stringent regulations being introduced for ship emissions there is an opportunity emerging that encourages the development of a future market for LPG as a marine bunker fuel. This is apart from the small recreational and commercial sector where LPG has already penetrated as an alternative to traditional marine fuels.

The application of LPG as a primary fuel for power generation ranges from 1kw to 300MW output. There is therefore no reason why LPG cannot be used in all sizes of vessels from boats with the smallest of outboard engines through to the largest of ships fitted with gas turbines.

The focus and pressure is now on marine emissions

The argument to displace these fuels with LPG in water borne vessels, based on improved emissions, is strong, but there are other benefits. LPG is a very clean fuel to store and handle ensuring spillages don't result in polluted waterways, coastal areas and open seas. LPG burns in the engine very cleanly too, resulting in less maintenance and longer engine life.

However, sea water presents corrosion challenges to the fuel system which must be managed by ensuring the system is well protected through marinisation (see also Chapter 9.0).

The bunkering infrastructure for natural gas is not mature whereas there are many bunkering facilities available for LPG around the world. If the vessel is carrying LPG as a cargo, there are opportunities to utilise that, and in doing so save bunkering time.

There will be a need for effective training of personnel, the introduction of proper procedures and the correct selection of equipment, to transfer, store and burn any gas aboard the vessel.

Chapter Three

Basic Properties of Liquefied Petroleum Gas

- LPG is portable and ideal for use as a marine transport fuel
- LPG has very good cold start properties
- LPG is clean to store and handle and burns with very low emissions
- **LPG is heavier than air and must be vented out of the vessel in the event of leaks**

The term Liquefied Petroleum Gas (LPG) is applied to mixtures of light hydrocarbons which can be liquefied under moderate pressure at normal temperature but are gaseous under normal atmospheric conditions.

Approximately 60% of the world's LPG comes from processing so-called 'conventional' natural gas. The remainder is mainly produced during the refining of crude oil. LPG is a by-product of both these processes but it has a range of properties that enables it to be used in hundreds of different applications, including the engines of prime movers.

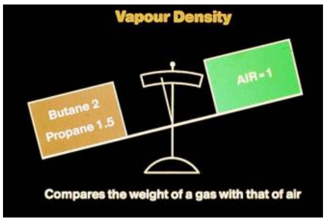
The main components of LPG are propane (C_3H_8) and butane (C_4H_{10}), mixed in any proportion, or with air.

LPG becomes liquid at room temperature if moderately compressed and reverts to gas when the pressure is sufficiently reduced. This important property gives them a considerable advantage over other fuels because they can be easily transported and stored in the liquid state.

An important property of LPG for use in water borne vessels is that it is portable and, when in vapour form, it is heavier than air. If LPG leaks it will always fall to the ground.

If LPG is used in a vessel and leaks, and is left unchecked, it will find its way to the engine room floor or bilge. LPG should therefore always be stored in a well-ventilated area where any leaks can be vented safely outside the vessel.

LPG has several unique properties that make it particularly suitable for use in water borne vessels.



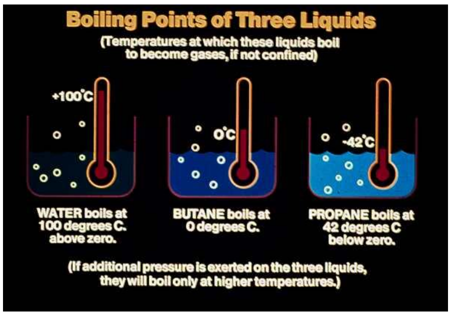
LPG is heavier than air

It has a high calorific value allowing a longer range between refills or bunkering.

In liquid form LPG is lighter than water. Because LPG is stored under pressure any leak will disperse without creating an environmental mess.

Propane will boil at minus 42 degrees centigrade which makes it more suitable than butane for cold climates. Butane boils at around zero degrees. LPG has very good cold start properties.

Liquid LPG has a high co-efficient of volumetric expansion which is why storage tanks and cylinders should never be allowed to become liquid full.



Propane can be used in circumstances where there are very low temperatures

An ullage or space, of around 20% of the total volume, must be left in the full container to allow liquid LPG to expand when temperature rises. This is especially important in the event of a fire.

LPG can be delivered in small quantities in tanks at relatively low pressure far from pipelines. Unlike natural gas (methane), which does not liquefy unless compressed at high pressures or low temperatures. This raises the cost of storage of natural gas, and increases the associated noise and safety issues.

LPG refilling or bunkering stations can be located close to water where deliveries can be made directly to vessels.

LPG burns cleaner in comparison to most other fuels. Unlike traditional marine fuels, which are very visible, LPG is a gas. LPG has no smell, but a powerful odorant, ethyl mercaptan, is added so that leaks can be detected easily by smell.

Chapter Four

LPG as an Engine Fuel

- **The safe handling of LPG on a vessel is critical**
- **Personnel involved with handling LPG as a marine fuel need to be competent**
- **LPG is a proven engine fuel producing very low emissions**
- **An extensive LPG infrastructure already exists to support a marine fuel business**
- **LPG is in abundant supply and forecasted to be so for some time**

First an important word about safety. The main safety challenges of using LPG as a fuel can be summarised as follows:

– LPG vapour is heavier than air and must be vented outside the vessel
– Any leak must not be allowed to collect to eliminate any fire and explosion risk
– LPG is flammable in the range of 2% to 10% mixture in air
– LPG is naturally odourless and colourless
– Low temperature burns can result from skin contact with liquid gas
– Ensure protection from the ship's side and bottom (collision and grounding)
– Ensure protection from external fire and BLEVE (boiling liquid expanding vapour explosion)
– Ensure protection from mechanical impact

These should all be considered as the basic principles in the safety philosophy and risk mitigation used in the design and operation of LPG fuelled vessels.

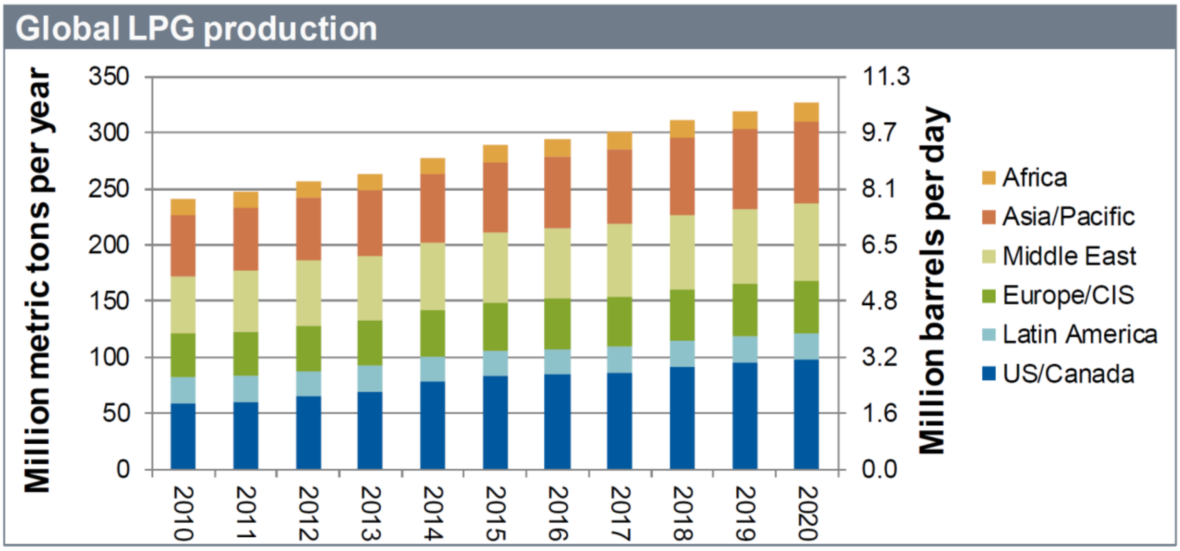
The competence, training and certification of the personnel involved in the design, maintenance, operation and emergencies related to LPG as a marine fuel are also critical factors.

There is an advantage, in the early stages of development, in utilising LPG as a marine fuel because there is already a highly-developed LPG distribution network already in place, unlike natural gas.

For larger vessels, the availability of higher quality cleaner fuel, and low emission exhaust gases, are particularly important as a business proposition as well as for the people that work in the ships engine rooms.

Currently LPG is predominately used as a transport fuel in land transport sectors. To integrate LPG into the marine sector should not be overly problematic, nor should it prove to be overly costly to initiate.

The supply position, and the forecast for the next few years, of LPG globally is very good. There are potential commercial benefits in utilising the abundance of available gas reserves as a marine fuel.



Source: with kind permission of IHS [www.ihs.com]

The ability to easily liquefy the gas and its relative safe means of transport has created a highly dense distribution network. This makes LPG commercial available at most ports around the world.

The increasing environmental concerns, coupled with the advanced knowledge of the potential health risks associated with burning carbon fuels, has driven policy makers to develop restrictions for limiting harmful emission that develop from burning these fuels.

The effects of exhaust emissions from ships in relation to total emissions in coastal areas are now better understood. This new knowledge is driving improvements of emission regulations. These new regulations are forcing the marine industry to come up with modified or new technologies. One option for meeting the demands for reduced emissions is to utilise gas, including LPG, as a marine fuel.

The technology that has been developed for main propulsion systems designed to burn LPG and use marine diesel oil as pilot fuel is very promising for the low speed engine market (see also Chapter 5.0).

Although the medium speed engine market has not been considered economically viable there is no reason to doubt technical development if the economics change to be more favourable.

The technology for using LPG in the petrol and diesel driven recreational boating market is already well developed and that segment is ready for further penetration by LPG as a cleaner alternative fuel.

Other possible segments include small ferries, tug boats and coast guard vessels with larger ocean going ships a larger target.

There are clear environmental and health benefits of using LPG as a marine fuel; reduced emissions of NOx, CO2, particulate matter and SOx.

For the shipping companies, there are the benefits in processing a green initiative and promoting a high environmental profile. There are operational benefits when using LPG fuel systems as the engine life is typically longer compared to marine fuel engines with less associated maintenance and longer intervals between engine overhauls.

LPG is readily portable and has exceptional engine burning properties which enables it to be easily used as a transport fuel.

It has a high octane number making it very suitable for spark ignition engines. For many years, LPG has been used in refineries as a gasoline blending component to enhance the octane number of gasoline. The base octane number of LPG is around 105 (RON) which can be up to 10 numbers higher than base gasoline.

But it can also be used in diesel engines as a blending component with diesel. Recent work has demonstrated that up to 30% of LPG can be blended into diesel without any problems.

Although there has been limited emissions testing done on diesel/LPG blends, the likelihood is that particulate emissions would be lower with LPG displacing some of the diesel.

LPG combustion can result in lower emissions of regulated pollutants and greenhouse gases compared to the more common liquid hydrocarbon fuels. If the pricing conditions are right using LPG to displace gasoline, diesel and fuel oil can realise both environmental and economic benefits.

LPG as propane can operate effectively at very low temperatures, well below freezing. The cold start performance of LPG is very good and there is no need for any form of artificial heat to be applied to start the engine under low ambient temperature conditions.

Engines running on gasoline or diesel can be difficult to start at these very low temperatures, especially diesel engines. Although gasoline engines can operate at low temperatures diesel engines cannot without some form of assistance.

When ambient temperatures drop below freezing, diesel fuel will start to crystalise and revert to a wax like structure. This phenomenon is explained in one of BP's fuel news leaflets. (http://www.bp.com/content/dam/bp-country/en_au/media/fuel-news/winter-diesel-problems.pdf).

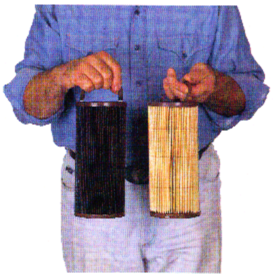
Diesel fuel wax

When diesel fuel waxes, it creates problems when trying to start the engine, especially first thing in the morning. Tiny crystalline particles of wax will emerge in the diesel and gradually build up to a point where they can block fuel lines, fuel filters and even damage the fuel filters. This waxing of diesel is particularly apparent when engines and fuel lines are exposed.

The wax can be removed by the application of heat but often diesel engines need to be run for several minutes to allow the fuel system and the temperature of the diesel in the tank to warm up. The spill back of the warm diesel fuel from the injector rail to the tank will achieve this.

Where low ambient temperatures are expected, the use of trace heating for the diesel fuel lines, and glow plugs in the engine to assist initial combustion, can be used.

Another advantage of LPG as an engine fuel for vessels is that it is kept under pressure. This prevents contamination of the fuel from external sources such as water. Fuel oil, diesel and gasoline fuel tanks on vessels are susceptible to water contamination and need to be regularly checked and drained.



Diesel fuel filter damaged by fuel degradation

Water is a very dangerous contaminant in a fuel oil, diesel and gasoline tank of an engine. Any water in the fuel can lead to engine failure and will also accelerate the process of internal corrosion leading to particles of rust forming in the fuel and fuel lines. This in turn can get drawn into the engine causing damage to the fuel system such as blocked filters and fuel injectors. If the ambient temperature falls below zero degrees centigrade any water in the fuel system will freeze and possibly block the fuel supply completely.

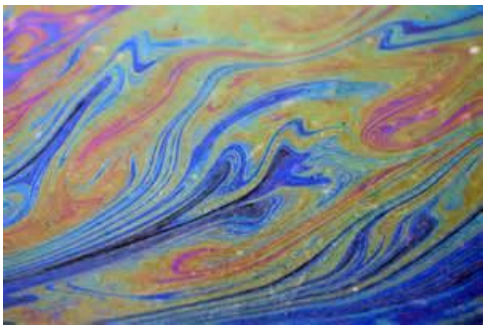
If water is left to remain in the fuel tank of a diesel engine it can lead to fuel degradation. Micro-organisms, bacteria and enzyme activity, fungus, yeast and mould can form. This will shorten the life of fuel filters and threaten the engine performance.

Traditional engine fuels such as gasoline and diesel have densities below that of water and so any water contamination will fall to the bottom of the fuel tank. With land based storage tanks the removal of water is relatively easy because conditions are static and the drain point is easy to access.

Removing water from a gasoline or diesel fuel tank on a vessel is more difficult because access is often restricted and the vessel will not be stationary unless dry docked. Any movement of the tank in the vessel will make it difficult for the water phase to remain stable and inevitably fuel will be drawn off too. Disposal of the drained material is a challenge, especially if the vessel is not near a disposal facility.

The drainage of LPG tanks on a vessel should not be required if the storage tanks at the refuelling facility have been regularly checked and drained.

The environmental argument to convert from gasoline and diesel to LPG is strong because narrow 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.



The result of an oil spillage on water

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 and subsequent financial claims.

Another benefit of an LPG marine engine is its quietness compared to a diesel engine which operates at higher compression ratios leading to increased noise. LPG fuel tanks are much less messy to refuel.

Chapter Five

Types of Vessels

- **Vessels have already transitioned from wind to steam to oil; the era of gas beckons**
- **There are three general categories of vessel described here:**
  - **Recreational (speed boats, house boats, …)**
  - **Commercial (fishing boats, ferries, harbor craft, …)**
  - **Large ocean going ships (cruise liners, container ships, very large gas carriers [VLGC's]…)**
- **And there are three main engine types**
  - **Low speed (<300rpm)**
  - **Medium speed (300-1000rpm)**
  - **High speed (>1000rpm)**
- **The marine bunker market is estimated to be close to 200mboe**
- **And is forecast to grow at 6% - 7%/year**

LPG is used as a fuel for power generating equipment in engines as small as 1kw generating capacity up to the largest gas turbines that can produce over 100MW. There is therefore no technical reason why LPG cannot be used in any water borne vessel; from the smallest recreational craft to the largest ocean going tankers.

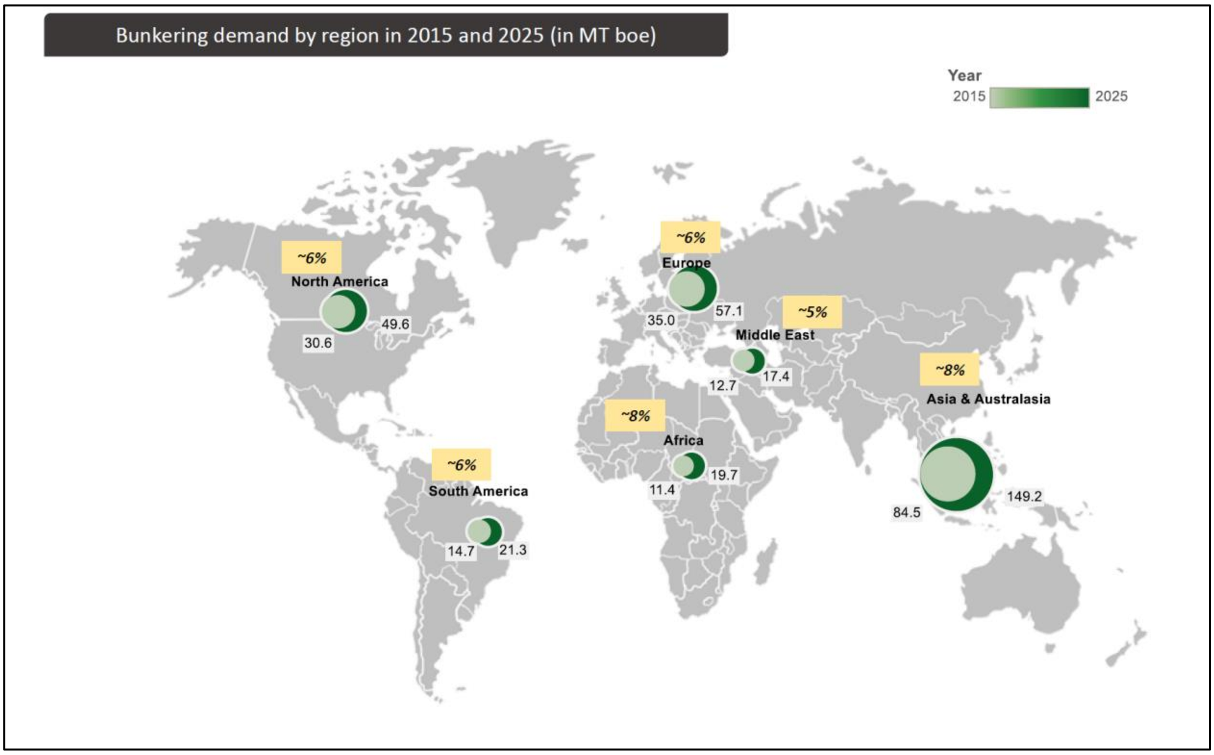
Engines classified as low speed typically operate up to 300rpm, medium speed engines typically operate in a range of 300 to 1000 rpm, and high speed engines operate at 1000 rpm and above.

Most of the gas engines on board the gas fuelled ships are medium speed engines.

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

The power range available for marine engines is from about 500 kW to almost 18,000 kW with up to 1000 kW/cylinder. Examples of major manufacturers with dual fuel four stroke engines for marine use are MAN, Wärtsila and Caterpillar.

Dual fuel two-stroke engines for the marine engine market could either be medium speed engines or low speed engines. MAN and Wärtsila are two companies that manufacture these type of engines.



Global bunker fuel market and forecast

The market for bunkers is large and growing, presenting an attractive segment for LPG. According to Galways, the growth in the marine bunker market is expected to grow from 189 million barrels of oil equivalent (mboe) in 2015 to 314mboe in 2025 representing growth rates around 6%/year.

Water borne vessels are generally distinguished based on size, shape and cargo, or passenger carrying capacity. Water borne vessels are found on lakes, rivers, waterways or canals, seas and oceans for a variety of activities, such as the transport of people or goods, fishing, recreational activities public safety and warfare.

5.1 Recreational Vessels

The use of LPG in recreational vessels, such as narrow boats, house boats and fishing boats, is not uncommon although gasoline and diesel engines would be the most likely form of propulsion. Some of these vessels would have in-board engines and others out-board engines.

LPG used to power this narrow boat can also be used for cooking and heating applications

LPG would often be the fuel of choice for cooking and space heating in recreational vessels supplying fuel to gas stoves and catalytic wall mounted heaters. Another application for LPG in recreational vessels that have living quarters, such as house boats, might be gas refrigerators.

The usage pattern for these boats would range from occasional use, to 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.

Other vessels that fall into the recreational craft category include those involved in water sports. Vessels such as speed or power boats, and water or jet skis. The most common fuel for these applications would normally be gasoline. They would typically be fitted with either four stroke or two stroke engines.

Outboard LPG engines in leisure craft

These types of boats would more likely operate in a seasonal pattern, with frequent use in summer months and possibly being dry docked during the winter.

The refuelling of recreational vessels that are used for domestic pleasure would typically be done at the moorings. But because 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.

5.2 Commercial Vessels

The types of craft that come under the category of commercial vessels are fishing boats, ferries and harbour craft. The size of engine for these craft are larger than those found in recreational vessels and more likely to be diesel.

Four stroke gasoline engines might be preferred in smaller fishing boats. Larger ferries might also use marine diesel engines or even fuel oil.

Commercial vessels such as ferries are more likely to operate to a regular schedule where movements are governed by timetables. This could be seasonal but it could also be a year-round activity.

Examples of LPG vessels (courtesy Lehr)

Ferries typically operate between fixed locations in a very repetitive pattern over relatively short distances. This not only allows for some good comparative trials to be done it creates an opportunity to establish a purpose designed base for refuelling.

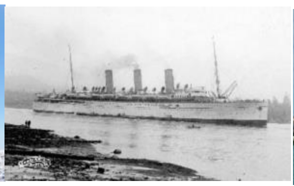
Commercial fishing boats however might be restricted to seasonal activity where they are only permitted to operate within certain periods for ecological reasons. Some might be at sea for extended periods - several days for example - requiring not only large fuel tanks but also the ability to refuel at sea. These boats would be larger and have sleeping quarters.

Other fishing boats might operate on a 24-hour cycle and return to shore with their catch and to refuel. These boats would be smaller.

5.3 Ships

The third category of water borne craft are ships. These can include ocean liners to large cargo vessels. The fuel used in these larger vessels is generally heavy fuel oil or marine diesel although some gas product carriers are now burning their cargo, especially LNG ships.

The development of propulsion methods for ships over the years has seen many great changes. The early ships were the first proponents of renewable energy with their reliance on wind.

Sail **Steam** **Oil** **Gas**

With the advent of steam power, these sailing ships quickly gave way to propulsion with coal fired boilers, generating steam and much more power, speed and manoeuvrability. However, this came with a cost in the form of the first ship emissions.

Later, oil fired reciprocating internal combustion engines were introduced using distillate fuels (marine diesel oil or MDO) and medium and heavy fuel oil. MDO was favoured for high speed engines with fuel oils being used for the medium and low speed engines. During the period when these engines and fuels were introduced there was little environmental concern for either greenhouse gases or exhaust emissions.

Consequently, the quality of MDO and marine fuel oils used was inferior to their land based equivalents. Even today the maximum sulphur limit for marine fuel oil is 3.5% compared to the sulphur levels in automotive diesel fuel being limited to parts per million.

These changes in propulsion have historically been driven by the need for increased power and quicker voyages but the more recent move away from oil to gas has been caused by increased pressure on emissions from ships.

Authorities are now monitoring emission levels from ships leading to restrictions to certain areas where they do not comply (see Chapter 9.0)

LPG and natural gas have major advantages over the use of MDO and HFO when it comes to emissions and provide a solution to these restricted areas.

Companies such as Wärtsilä claim to have '…close to three decades of experience in gas, over 2,000 marine gas engines, millions of operating hours and tens of millions of horsepower…' They claim they '…have a proven track record in gas technology and gas systems…'

Wärtsilä go on to say '…while operators may be hesitant to make major investments on large-scale vessels and terminals now, small-scale gas options represent a less risky, more flexible alternative, for a growing market…'

Chapter Six

Why LPG for Vessels

- **LPG is a proven transport fuel with 26 million vehicles running on LPG in 2015**
- **LPG is an excellent fuel for marine applications**
- **It presents an opportunity now for displacing some highly polluting marine fuels**
- **VLGC's carrying LPG could utilise the cargo eliminating the need/time to bunker**
- **The use of LPG reduces engine maintenance**
- **For smaller vessels LPG can also be used for cooking, heating etc.**

LPG has extremely good properties for use in engines. It is clean to handle, has a very low carbon footprint and produces less emissions that traditional engine fuels.

There are over 26 million vehicles running on LPG (Autogas) today producing much lower exhaust emissions than their diesel and gasoline counterparts and contributing to cleaner urban air quality.

LPG has an octane number rating higher than gasoline making it an easy choice as an alternative fuel in road and off road vehicles. Boats fitted with spark ignition engines can be easily converted to run on LPG.

With all the concern on diesel emissions LPG has become increasingly popular as an alternative to diesel, either in part, as a blended fuel, or in total through an engine replacement programme or conversion technology.

Governments encourage the use of Autogas for several reasons. Urban air quality might need improvement. There might be a need to reduce the dependency on diesel and gasoline for strategic reasons. Or there might be a surplus of local LPG production. Similar arguments apply for water borne vessels.

There are various tools available to encourage the use of Autogas. The main incentive for the vehicle owner will be cost.

The tools available to governments might include fiscal measures to reduce the tax on LPG; or to raise it on diesel and gasoline. Governments might issue grants for converting engines to run on LPG instead of gasoline and diesel. In inner urban areas vehicles running on Autogas might be exempt from congestion charges.

These financial incentives are unlikely to be available for the boat or ship owner and so the main incentive to use Autogas for the vehicle owner lies elsewhere.

The cost of fuel may not be such a priority for recreational users. Having just one fuel available on a boat might be a convenience. LPG can not only run the main engine and power generator it can also provide the fuel for the galley for cooking and heating water.

There might be restrictions on the use of diesel and gasoline on inland waterways for environmental reasons and this might encourage the use of LPG.

Another reason might be to make a personal environmental statement.

For commercial boats and ships, the cost of fuel is likely to be a major component of the running costs.

Another reason to use LPG might be to meet the increasing emission standards being imposed by authorities such as the IMO.

If LPG cargo carrying vessels such as VLGC's were to utilise the cargo as bunker fuel it would eliminate the time the vessel is idle when bunkering. This can typically take several hours.

Engines running on LPG not only produce less exhaust emissions they are clean internally as well. Maintenance costs are lower and LPG engines have excellent 'cold start' properties and operate very well at low temperatures.

LEG Carrier fitted with dual fuel engine

According to a report in the Guardian newspaper based on information from the marine industry (https://www.theguardian.com/environment/2009/apr/09/shipping-pollution), just fifteen of the world's biggest ships may now emit as much pollution as all the world's 760 million cars.

Low-grade ship bunker fuel (or heavy fuel oil) has up to 2,000 times the sulphur content of diesel fuel used in US and European automobiles. This presents a strong case for action.

Some manufacturers have already designed engines to run on LPG for recreational vessels.

Although the engines on recreational vessels typically run on gasoline and diesel they all have the capability to be converted to LPG.

Emissions from ships are no longer being ignored

In some cases, there might be some compelling environmental reasons to switch to LPG. Perhaps restrictions on the use of gasoline or diesel in certain inland waterways. Or perhaps the justification to convert these engines to run on LPG will be mainly based on the relative cost of LPG to diesel or gasoline.

A key concern for users in this category - either choosing, or switching to LPG - would be performance. Power output and torque from the engine is important for these types of applications and engines running on LPG would be under scrutiny for comparable performance.

The prerequisite for change of an industry fuel of choice for the marine market can be divided onto three fields:

(i) Policy change like the strengthening of emission regulations and creating Emission Controlled Areas (ECA)
(ii) Technology innovation, with the development of gas fuelled engines
(iii) The price and availability of the fuel

The policy change is starting to be applied and is not just limited to Europe and the USA with their 'Sulphur Emission Controlled Areas' (SECA). Other governments such as Canada, Japan and Australia, have discussed or are planning to create (ECA) zones along their coastlines.

Today all major manufacturers of marine engines are developing technology for utilising gas as fuel. Currently one of the major engine manufacturers has commissioned a low speed engine that is certified for operation on LPG. It is likely that same manufacturer will develop the same option for their customers for the medium speed engine market as soon as it is economically viable.

Although bunkering facilities for natural gas are limited there are plans to develop the network further. LPG has already a strong sea fed network around the world and adapting that for bunkering ships with LPG would not be difficult.

There is an argument for standardising the bunkering connection for LPG to avoid the issues that have developed over time with Autogas connections in Europe.

Chapter Seven

Use of LPG in Vessels

- **No technical reason why LPG cannot be used as a marine fuel in all types of vessel**
- **LPG for new builds is preferable because of the venting issues with retrofitting**
- **The forecast for LNG fueled ships is strong**
- **IMO emission factors (MTCO2/MT fuel) favours gas over traditional marine fuels**

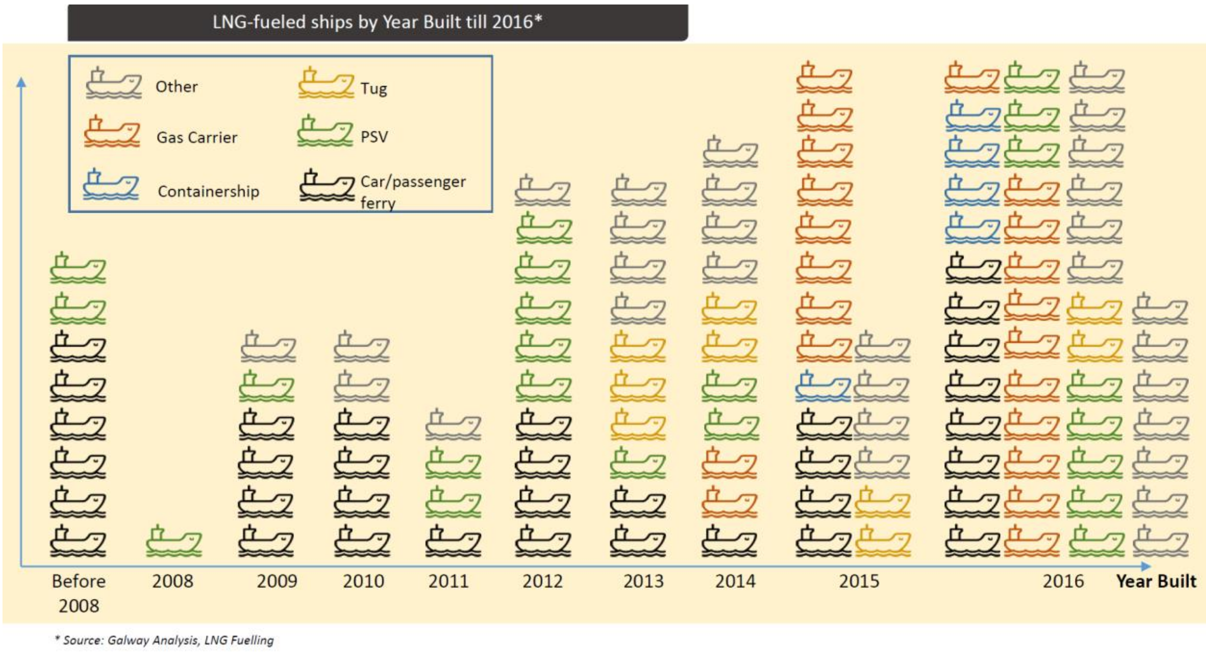
There is no technical reason why LPG cannot be used in vessels. There is no doubt though that retrofitting a vessel designed for traditional marine fuels, or even natural gas, would be challenging because of the mitigating measures needed to cope with the event of a leak of LPG, especially in the engine compartment or engine room. The location of the LPG storage tanks and fuel lines on board would also have to be carefully chosen for the same reasons.

It is a different matter for new builds that have been designed for LPG. All the necessary precautions can be taken in the design to prevent any build-up of LPG in low areas and ensure any leaks escape safely overboard.

An incentive for using LPG in large LPG gas carriers (VLGC's) would be to eliminate the time taken for bunkering as the engine would be burning the cargo. Currently on these vessels there is a compressor/chiller to liquidise and feed back into the main cargo area any cargo vapour. This facility could even be designed out if the vessel is burning LPG.

Internationally 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. This design is intended for service in the port of Long Beach and in the Port of Los Angelis (Cavalier).

There are already many vessels running on gas. According to Galway there will be over 100 LNG fuelled vessels by the end of 2016 with more on order.



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.

There has been much discussion recently about the use of gas as a bunker fuel for large ships. This has been driven mainly by the potential use of natural gas.

A new mandatory code for gas-fuelled ships is set to be adopted by the IMO's Maritime Safety Committee (MSC), the IMO has announced.

The organisation said that as ships increasingly adopt gas fuel such as LNG, the need for broader regulation and standard practices has become more important.

The new International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) will reportedly have an initial focus on LNG, and will "provide mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuels."

Fuel Type	IMO emission factors (in tons of CO2/ton of fuel
Heavy Fuel Oil – ISO 8217 RME - RMK	3.114
Light Fuel Oil – ISO 8217 RMA - RMD	3.151
MDO/Gas Oil – ISO 8217 DMX - DMB	3.206
LPG - Butane	3.030
LPG - Propane	3.000
LNG - Methane	2.750
Methanol	1.375
Ethanol	1.913
Hydrogen	zero

IMO emission factors

A shipowner is faced with several options when deciding on the type a fuel to use. The chart above shows some of those options together the level of emissions the vessel emits in metric tonnes of CO_2 per tonne of fuel consumed. LPG fares better than MDO and fuel oil but is not as good as methanol and ethanol.

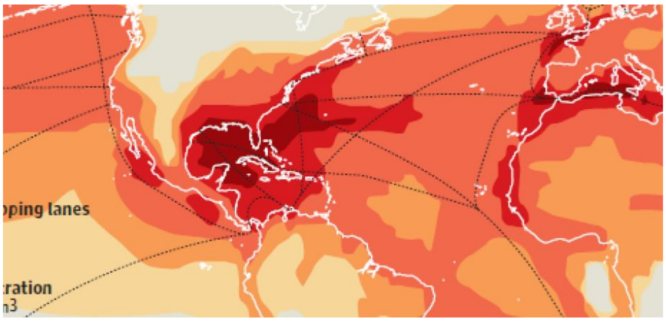
Chapter Eight

Recent Emissions Regulations

- **Severe PM pollution is clear on emission maps of global shipping routes**
- **IMO implementing a global cap on Sulphur in HFO of 0.5% by 2020(3.5% now)**
- **ExxonMobil are forecasting by 2014 10% of all bunker fuels will be gas**
- **Emission Control Areas (ECA's) already in place in Europe and USA**
- **Other countries considering introducing them (China, Australia…)**

With the focus of attention for the last few decades on road transport emissions, which has led to significant improvements in the quality of gasoline and diesel, the quality of marine fuels has been largely ignored.

As a result, the emissions from marine traffic has not only worsened, with the increased number of ships and sea miles travelled, the impact of the pollution is more evident. The spotlight is now on how to improve air quality on major shipping lanes and this opens a big opportunity for cleaner gaseous fuels to displace these marine fuels.



Particulate Matter pollution overlaid on the world's major shipping routes Source: (American Chemical Society 2007)

According to the International IMO, ocean-going ships released 25.8 million metric tons of nitrogen oxides in 2007. These emissions are projected to increase to 34.2 million metric tons by 2050 (Eyring *et al*, 2007).

In the ExxonMobil Outlook for Energy – A View to 2014 it states '…We also anticipate natural gas demand in the marine sector to increase significantly, stimulated by new emission standards. By 2040, gas is likely to account for about 10% of total marine fuels, up from 1% now, with about two thirds of the growth in developing countries…'
(http://corporate.exxonmobil.com/en/energy/energy-outlook)

In a landmark decision for both the environment and human health, 1 January 2020 has been set as the implementation date for a significant reduction in the sulphur content of the fuel oil used by ships (http://www.imo.org/en/MediaCentre/PressBriefings/Pages/MEPC-70-2020sulphur.aspx)

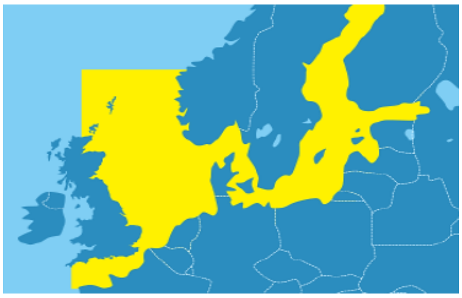
The decision to implement a global sulphur cap of 0.50% m/m (mass/mass) in 2020 was taken by the IMO, the regulatory authority for international shipping, during its Marine Environment Protection Committee (MEPC), meeting for its 70th session in London.

It represents a significant cut from the 3.5% m/m global limit currently in place and demonstrates a clear commitment by IMO to ensuring shipping meets its environmental obligations.

IMO headquarters in London

IMO Secretary-General Kitack Lim welcomed the decision which he said reflected the organisation's determination to ensure that international shipping remains the most environmentally sound mode of transport.

"The reductions in sulphur oxide emissions resulting from the lower global sulphur cap are expected to have a significant beneficial impact on the environment and on human health, particularly that of people living in port cities and coastal communities, beyond the existing emission control areas," Mr. Lim said.



Currently Europe has a SECA that covers The Baltic Sea, North Sea and The English Channel

The Sulphur Emission Control Areas (SECA's) or Emission Control Areas (ECA's) are sea areas in which stricter controls were established to minimise airborne emissions (SOx, NOx, ODS, VOC) from ships as defined by Annex VI of the 1997 MARPOL Protocol which came into effect in May 2005.

Annex VI contains provisions for two sets of emission and fuel quality requirements regarding SOx and PM, or NOx, a global requirement and more stringent controls in special Emission Control Areas (ECA). These regulations stemmed from concerns about the contribution of the shipping industry to "local and global air pollution and environmental problems." By July 2010 a revised more stringent Annex VI was enforced with significantly tightened emissions limits.

In addition to Sox limits, the North American ECA has limits on the NOx emissions as well (known as a NECA)

As of 2011 there were four existing ECAs: the Baltic Sea, the North Sea, the North American ECA, including most of US and Canadian coast and the US Caribbean ECA. Also, other areas may be added via protocol defined in Annex VI. ECAs with nitrogen oxides thresholds are denoted as Nitrogen Oxide Emission Control Areas (NECAs).

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

The impact of this on fuel prices is unclear but it is likely that these lower sulphur fuels will be more expensive and make gas a more attractive, low emission option, to meet these new limits.

Chapter Nine

Key Design Features for Marine Applications

- **LPG is heavier than air and that must be managed on board**
- **Any LPG leaks must be taken outside the vessel**
- **Engines and equipment need to be marinised to prevent (salt) water corrosion**
- **Three key considerations when designing a vessel for LPG:**
  - **Corrosion**
  - **Vibration**
  - **Movement**
- **Small vessels can utilise traditional LPG supply networks**
- **Larger ships will need infrastructure although much exists already**

It is critical that the storage of LPG on a vessel must consider the 'heavier than air' property from the filling or bunkering process through to combustion.

Any potential leak from the whole fuel system must be directed in a way that prevents the gas from remaining inside the vessel, especially the engine room floor or bilges.

The space required to store LPG on board will be larger than that needed for traditional fuels and may present a challenge in some markets where the vessel has limited space. This is because of the need to match the same range as traditional fuels.

The shape of the tank, being a pressure vessel may also present a challenge. Especially when retrofitting a vessel to LPG.

New vessels will be able to take advantage of the otherwise unusable space in a vessel to install the fuel tank.

A series of LPG cylinders fitted to a fishing boat and vented to the outside of the vessel (courtesy Lehr)

Small recreational vessels can use domestic cylinders which are swapped when empty. The harsh, salt water, environment makes it an ideal application for composite cylinders which are virtually corrosive resistant.

Outboard engine supplied with LPG (like a fork lift truck) (courtesy Lehr)

The cylinder shown here is in a horizontal position, like a fork lift truck.

Marine engines and fuel systems operating in water borne vessels need to be protected from the harsh conditions they will experience, especially at sea where the water is very saline.

The process to achieve this is called "marinising" and is done through design, or redesign, including the testing of products specifically required for long term survival in a harsh marine environment.

There are three main factors that need to be considered:

(i) Corrosion
(ii) Vibration
(iii) Constant movement of the vessel

Marinising the engine and fuel system prevents corrosion like this (courtesy Lehr)

The use of corrosion resistant alloys and stainless steel, galvanising and coatings and commonly used materials and techniques.

The additional cost of utilising these materials will be outweighed by the damage caused by not applying them and needing to replace components.

The consequential impact of failure of these components when out on the water could be disastrous.

If an engine is to be converted to LPG a thorough inspection of the vessels engine and fuel system should be done before any decision is made to proceed. If the engine is mechanically sound it will continue to perform well when converted. Some of the checks might include:

- Engine hours
- Service history (regular oil/filter changes)
- Engine performance (smoke, noise, operating temperature)
- Engine appearance (evidence of oil leak, fuel contamination)
- Spark plug condition (oil fouling)
- Cylinder compression test

Chapter Ten

LPG vs. Traditional Engine Fuels (including CNG)

- **Several grades of marine fuel oil (MGO, MDO, DO,MFO & HFO)**
- **All have relaxed limits on Sulphur and other contaminants**
- **There are several different types of engines**
- **LPG ranks well against all fuels including natural gas**

There are at least four main grades of liquid marine fuels including marine gas oil (MGO), marine diesel oil (MDO or DO), marine fuel oil (MFO or FO) and heavy fuel oil (HFO).

MGO is marine gas oil – DMA and DMX grades. DMA and DMX are the highest quality distillate normally supplied for marine use.

MDO is marine diesel oil – DMB and DMC grades. DMB is a Distillate Diesel Oil, DMC is a Blended Diesel Oil.

Advantages : LPG vs. CNG

	LPG	CNG
Recreational Marine Use	✓	
Commercial Marine Use	✓	✓
Efficiency	✓	✓
Operating Cost		✓
Investment Cost	✓	
Ease of Refueling	✓	

A chart summarising the relative advantages of LPG over CNG

(courtesy Lehr)

MFO is a blend of MDO and HFO. HFO is marine heavy fuel oil - Residual Marine (RM) grade.

HFO is the most common bunker fuel and is the least expensive fuel option.

Increasing limitations on the use of conventional fuels presents opportunities for gas in this sector.

When comparing the gaseous options the arguments are similar to those discussing the options for a small fleet of trucks.

There the options are often a choice between natural gas and LPG. In the road transport sector issues such as availability of refuelling facilities, range, and cost of conversion are often the key issues. The same applies to water borne craft.

For small vessels operating inland or close to the coast, the arguments favour LPG because of the limited availability of refuelling infrastructure. For larger vessels where these refuelling facilities exist the arguments might favour natural gas. However, the abundance of sea fed LPG facilities around the world currently makes LPG an attractive option.

Engine Type	Pros & Cons
Diesel direct drive / liquid fuel	Efficient established option with global fuel availability. Higher CO2 emission.
Diesel direct drive (MEGI) / methane	New technology, lower CO2 emission, evolving supply infrastructure for ships other than LNGCs.
DFDE / liquid fuel or methane with pilot fuel	Established and flexible technology, lower CO2 emission, evolving supply infrastructure for ships other than LNGCs.
Steam turbine direct drive** / liquid fuel or methane ** via gearbox	Established option for LNGCs, may be less efficient, lower emissions if using gas. Modern systems provide efficiency gains.
Gas turbine direct** or electric drive / liquid fuel or methane	Established option. New technology can improve efficiency and emissions running on gas.
Electric direct or pod drive / battery	Limited range, zero emission and ideal for small craft on predictable short routes.
Electric direct or pod drive / fuel cell	The zero emission future for many modes of transport when hydrogen production becomes more economic and infrastructure evolves.

Different propulsion options

Whatever the choice it is important to ensure operators have a comprehensive knowledge of the applicable rules and regulations for gaseous fuels.

This will include storage tank, pipe systems and ventilation. The safety-related aspects of a gas fuelled propulsion system. The impact of different ship types on the operations.

Chapter Eleven

Case Studies

- **There are several examples of where LPG has been used successfully as a marine fuel**
- **Wärtsilä is one of the gas champions for marine applications**

11.1 Wärtsilä

The following was taken from (http://www.wartsila.com/media/news/07-06-2013-wartsila-aquarius-uv-ballast-water-management-system-to-be-retrofitted-to-lpg-vessel).

Wärtsilä has been contracted to retrofit its Wärtsilä AQUARIUS®UV ballast water management system for the 'Marola', a 37,000cbm fully refrigerated Liquefied Petroleum Gas (LPG) vessel of the Carbofin SPA, Italy fleet. Carbofin is part of the Carboflotta Group. The retrofitting for the 'Marola' took place in autumn 2013 when the ship was dry docked. The vessel operates in the U.S. Gulf of Mexico, the Caribbean, and South American waters.

By virtue of its design, the Wärtsilä AQUARIUS®UV ballast water management system allows ease of installation for both retrofit and new build applications. The system can be tailored to meet specific requirements, while enabling conformity with legislation and helping owners and operators to minimize their environmental footprint.

Wärtsilä Environmental Solutions offers complete services for retrofit projects. The offering is modular and flexible: depending on customer's needs the retrofit project scope can vary from a simple equipment delivery to a complete turnkey project where Wärtsilä is responsible also for the installation works. In this specific project, in addition to the equipment Wärtsilä is providing engineering support, commissioning and start-up.

"Our company is conscious of the responsibilities involved in protecting the environment. Our policy is to constantly improve our own environmental services, and to reduce marine pollution by minimising the risk of emissions and harmful releases. By retrofitting Wärtsilä's AQUARIUS® ballast water management system to the 'Marola', we can be assured of conforming to legislation, as well as protecting and safeguarding the environment in sensitive areas around the world," says Roberto Saia, Technical Manager, Carboflotta.

"Ballast water management is becoming increasingly important for the industry. At Wärtsilä, we have worked hard to develop technologies that are reliable, efficient, and which promote environmental sustainability. We have a very good working relationship with the Carboflotta Group, for whom we have successfully supplied solutions for more than 25 years," says Juha Kytölä, Vice President, Environmental Solutions, Wärtsilä Ship Power.

Ratification of the IMO's Ballast Water Management Convention, which will require the owners of up to 40,000 vessels worldwide to install a ballast water management system (BWMS) was adopted by consensus at a Diplomatic Conference held at IMO Headquarters in London on 13 February 2004 after more than 14 years of complex negotiations between IMO Member States, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention).

The US Coast Guard (USCG) has however implemented their own legislation which states that all ships will have to be in compliance with the regulations when sailing in US coastal waters. Enforcement of the US requirement commenced on 19 December 2013, when ships must comply with the 2013 Vessel General Permit (VGP) regulating discharges from ships. As a consequence, ship owners have to evaluate the ballast water treatment technology best suited to both their existing and new ships. The intention of the legislation is to address the issue of invasive aquatic species being carried in the ballast water of ships and then discharged to the sea where they can harm local species.

11.2 Italy

The Civitas project in Venice, Italy, shows an interesting development for LPG as a marine fuel for the petrol-driven private recreational boat markets.

For that market to be viable it is necessary to open dedicated filling stations to serve that segment. The price incentive between petrol and LPG is the same as for the land transport.

LPG has been introduced on the private and leisure boat market through the Civitas project in Venice.

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

An LPG-dedicated floating filling station

Chapter Twelve

Conclusions

- Environmental and economic benefits of using gas as a fuel for shipping has created a lot of interest in the business community and among other stakeholders including federal and local governments, industry groups, and environmental organisations
- The main driver is the IMO regulations, the anticipated abundance of gas and LPG supplies and the relatively low cost of natural gas compared to oil-based fuels
- The North American and European ECA's are areas of high shipping activity, both with respect to international and domestic vessel traffic, and putting the focus on marine emissions in those areas
- This is creating opportunities for LPG as a clean alternative to traditional marine fuels
- Early adopters in both USA and Canada have embraced the technology and benefits of using gas as fuel for ships
- Many of the gas fuelled vessels on order are ocean going cargo vessels and the prospects look good for further growth
- There are also opportunities for fuelling the recreational and commercial vessels with LPG but the volumes will not be so large
- Using LPG in boats and ships requires careful attention to safety especially when designing to disperse any leaks and training personnel

References

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IMO	(http://IMO.org)

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