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ANALYSIS OF THE ENTRY INTO FORCE OF THE USE OF FUEL LOW SULFUR TO THE MARPOL ANNEX VI, AND ITS INFLUENCE ON THE ASSETS SHIPS AND NEW CONSTRUCTION

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Abstract. Although the fuel used in maritime transport accounts for approximately 4% of the total consumed in the world, most shipping routes pass near the coasts of maritime shipping countries, and in some cases as The Channel, The Straits Gibraltar The Strait of Malacca, etc. With a very high density of maritime traffic and near the coast, makes much of air pollution from ships landing on the shores of the countries where they navigate, causing, among other effects, acid rain.
The MARPOL Annex VI requires that from 1 January 2015 the sulphur content in fuels used by the main and auxiliary engines of ships operating in ECA areas less than 0.1%.
Also from January 1, 2012, the same annex, has forced international shipping vessels than the maximum sulphur content of these fuels is 3.5%, and from 2020 will be lowered to 0.5%.
The above measures have caused a tsunami in shipping, for strict compliance with the rules set in the Annex VI of MARPOL, for the ECA areas, ships sailing in it, requires shipowners to use fuel with sulphur content less than 0.1%, which makes it necessary to use MGO fuel between 40-55% more expensive than HFO, which makes the ship operating costs skyrocket, and therefore, shipping is more expensive, leading in some cases the change of shipping to road transport.
Due to the above stated reasons, the shipowners have to make the decision to continue using HFO that meet specified in Annex VI of MARPOL, or change to other fuel that also comply with these regulations. For this there are several possibilities:
1st Use high sulphur HFO fuel and install systems for exhaust gas cleaning, scrubbers, to remove the sulphur they contain.
2nd Use of dual fuel engines that burn LNG, that do not contain sulphur.
3rd Use HFO fuel with low sulphur content.
4th Using biofuels.
In this paper we study the alternatives, with all its advantages and disadvantages, which can be used in existing ships and new construction in a manner that allows the owners thereof, that they comply with the rules of fuel use low sulphur content, regardless of the navigation zone because, from 2020 the global minimum content is 0.5%, this amount, near 0.1%, and therefore is desirable to have means to allow the use of low-cost fuels and sulphur, and doing that maritime transport be more respect with the environment.

Key words: energy efficiency, energy management, energy policy, shipping economic

1 ASSESS THE EVOLUTION IN RETROFITTING OF VESSELS VERSUS NEW BUILDINGS USING ALTERNATIVE FUELS AND THE POTENTIALITY OF NEW TECHNOLOGIES

1.1 Retrofit solutions as potential alternatives for new Sulphur regulation

Besides using alternative low sulphur content fuels, LNG fuel, methanol, liquefied petroleum gas (LPG) or biofuels which whilst potentially attractive to new build projects, there are two additional compliance methods that involve retrofitting of vessels; that is:

1. Introducing exhaust gas cleaning technologies to remove SOx from emissions. Two effective and mature technologies could be widely used (wet and dry scrubbing). A third, less mature option is non-thermal plasma.
2. Converting to Dual Fuel engines and install LNG Tanks

Table 1 shows the main features of both retrofitting options regarding financial, technical and regulatory issues, that is:

Table 1 Financial, technical and regulatory issues of retrofit options

Compliance method	Financial issues	Technical issues	Regulatory issues
Exhaust gas cleaning technologies: scrubbers	Financial loss due to the need to pause the operation of a ship, approximately for one month, in order to fit scrubbers onboard. Shipowners stressed that retrofitting for compliance methods requires high investments. For many shipowners this option is not feasible because there is no financial support by the private entities, therefore such projects are only feasible if there is financial support programs. The investment costs ranges from 100-200 €/kW for new installations and from 200-400€/kW for retrofit installations. In other words, it is about 1.2 to 2.2 M€ for new vessels and from 2.2 to 4.5 M€ for retrofit vessels. However, other sources said that the investment cost is 10M$ for an engine of 10,000kW. Then we should consider an additional use of fuel about 2%, maintenance cost (about 0.5-0.7 million €/year) and purchasing cost of NaOH and fresh water for closed systems and cost for disposal of sludge. Due to the vessel lifetime is 20 years on average it is just recommended for new ongoing vessels since the amortization period is about 3 to 5 years.	Companies are facing various technical challenges, since the installation of a scrubber is complicated due to the size of such equipment (mainly in small vessels). Also the weight and the impact of this technology onboard should not be underestimated.	There is a currently lack of regularity clarity on whether the discharge of was water and bleed off water is permitted in ports of the world or the EU ports due to conflict between the Water Framework Directive and the Sulphur Directive. In fact, wet scrubbing is associated with wash water discharge that this was water is subject to internationally agreed controls for pH<6.5, PAH and turbidity which are continuously monitored and recorded (MEPC 184(59)).
Converting to dual fuel engines and LNG tanks	Financial loss due to the need to pause the operation of a ship, approximately for 75 days, in order to fit scrubbers onboard. The converting cost, which includes engines and fuel tanks, is very costly. If the engines are substituted the cost could reach the 25-30% of the total vessel cost whereas it will be about the 10% if the engine is just adapted.	Dual engines will be able to consume both HFO and LNG fuel, according to the regulation applied. In practice, all vessels can be converted where available space (key factor) exists for the LNG tanks onboard the vessel. But, the installation of the LNG tanks will reduce the vessel capacity because the LNG cannot be stored in the double bottom tanks. It must be stored in independent tanks. It requires about 1.8 times more volume than MDO with equally energy content. But if the tank insulation is need, then the volume is about 2.3 times higher[1].	The use of LNG involve compliance for a range of potential future legislation (SOx, GHG, harmful particulates). Burning LNG produces 85-90% less NOx than the conventional fuel, and GHG emissions are reduced by 15-20%.

[1] TransBaltic (2012). Implications of new regulation regarding sulphur content in ship's fuel on maritime transport sector within Baltic Sea Region. Baltic Ports Organization Secretariat.

Mentioned options are recommended for vessels operating in ECAs sea basins. However, for ocean-going vessels that operates periodically with ports and stays for short periods in ECAs it is suggested to use low-sulphur content fuels and assume higher rates instead of doing a large investment to transform its engines.

2 FUEL PRICE EVOLUTION AND OPERATING COST INCREASES

During the last years, the cost of bunkering fuel has been characterized by large fluctuations. Despite the dip in 2009, an increasing trend has been observed until last months of 2014, when oil price collapsed. Figure 1 shows this price evolution from the nineties.

As it can be observed, at the beginning of the nineties bunker price was rather low so the difference per tonne between HFO and distillates was not too high and was about 50-100 USD per barrel. As the bunker prices increased the difference deepened. According to the evolution depicted in previous figure, distillates fuels were from 30 to 100% more expensive than HFO.

Additionally, from the 1st January 2015, low-sulphur content fuels (0.1%) gets more importance in ECA areas. The differences per metric tonne between those fuels and HFO or MGO are depicted in figure 2.

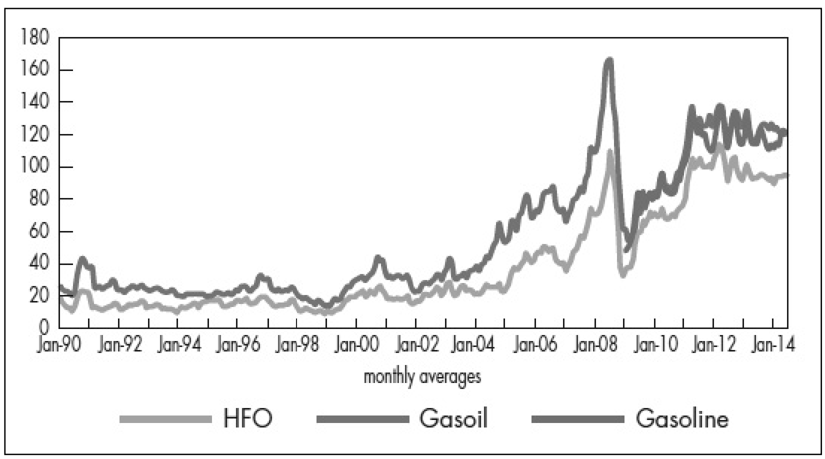


Figure 1 Rotterdam bunker oil prices (USD/barrel) evolution from the nineties
Source: Key World Energy Statistics, IEA (2014)

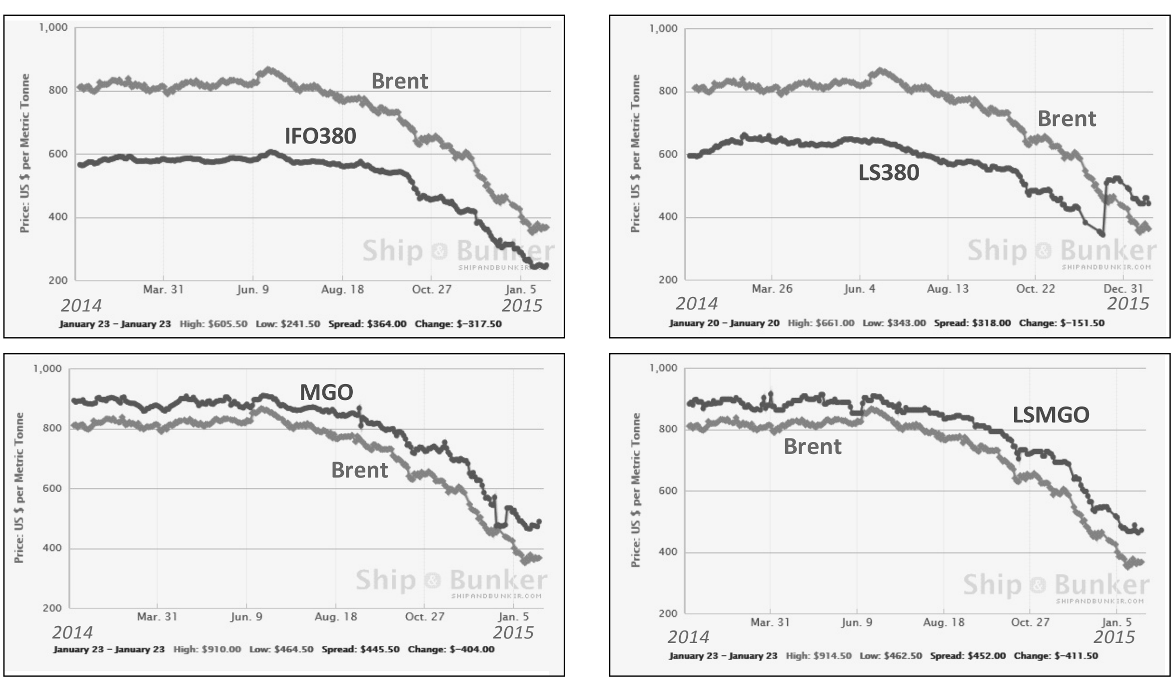


Figure 2 Rotterdam bunker and Brent price ($/metric tonne) evolution from January 2014 to January 2015.
Source: www.shipandbunker.com

Table 2 Daily prices (metric tonnes) of by Ships and Bunker for the port of Rotterdam (23th January 2015)

Type of fuel		Price	Change (vs. non LS)	Change (vs. LS MGO price)
HFO	IFO 380	247,50 $/mt	-	+90%
	IFO 180	280,50 $/mt	-	+68%
Marine diesel	MGO	489,00 $/mt	-	-4%
Low-sulphur fuels	LS380	442,50 $/mt	+79%	-
	LS180	366,50 $/mt	+31%	-
	LSMGO	471,00 $/mt	-4%	-

Figure 2 shows the evolution of daily prices reported by Ship and Bunker for the port of Rotterdam during 2014. For instance, the price differences registered the 23th of January 2015 in the port of Rotterdam (Table 2).

As it can be observed, there are large differences between low-sulphur fuels (0.1%) and conventional HFO fuels, while differences between marine diesel prices are small. Actually, at mid December 2014, LS380 prices increased drastically while IFO380 kept decreasing. Thus, price differences between low-sulphur and non low-sulphur are currently about 80% for LS380, while for LS180 price change is lower (about 40%).

2.1 Low-sulphur fuel prices projections

The future price of low-sulphur content fuels is unforeseen and different projections have been made. The Table 3 summarize most relevant.

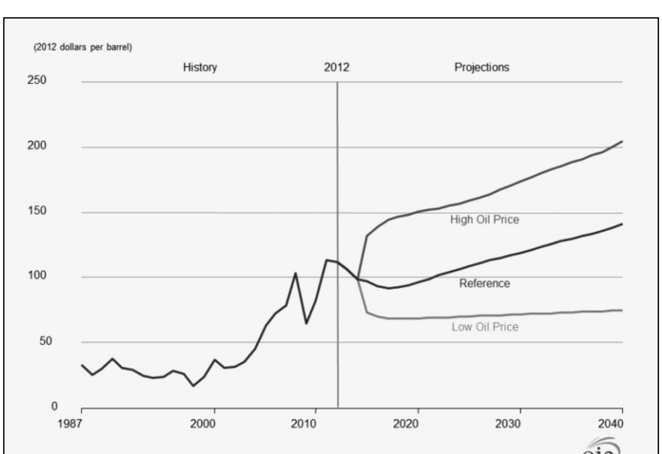
2.2 LNG price projections

The future price of LNG as shipping fuel is also uncertain. Its price may be indexed to that of oil, as is the case for most current long-term LNG contracts. Similarly to Table 3, the Table 4 shows the different price projections assumed.

Table 3 Fuel price projections by 2025.

Source/Study	Projections
Maritime Fuel Price and Uptake Projections to 2035 (based on energy and fuel projections produced by the OECD, the International Energy Agency (IEA) and the US Energy Information Administration (EIA). (see Figure 3)	The variation in HFO prices is correlated to the movement of oil prices. Its prices will range between $350 per tonne to $1,000 per tonne in 2015, and from $300 to $1,200 per tonne, in 2025. MGO prices will range between approximately $500 ($12/mmBTU) per tonne and $1,500 ($37/mmBTU) in 2015, and from $480 to $1,800 per tonne by 2025.
DECC Fossil Fuel Price Projections (2013)	Three different scenarios are defined to project oil price evolution: central, high and low. The projections are sense-checked against external forecasts such as those made by the IEA and EIA.

Source: OECD, IEA, EIA



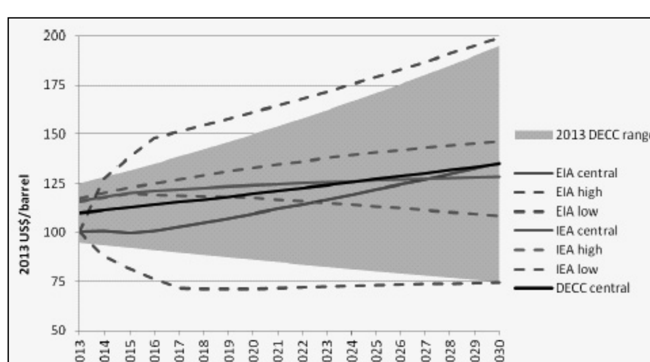


Figure 3 Energy prices projections by EIA ($ per barrel) and DECC (2013). **Source:** www.eia.gov

Table 4 LNG price projections by 2025.

Source/Study	Projections
Maritime Fuel Price and Uptake Projections to 2035 (based on energy and fuel projections produced by the OECD, the International Energy Agency (IEA) and the US Energy Information Administration (EIA).	LNG prices evolution goes from 320 to 800$ per tonne (7 to 17$/mmBTU) in 2015 to the range of 400-1200 US$ per tonne (9 to 26$/mmBTU) in 2025.
World Ports Climate Initiative (WPCI). IAPH – Port Environment Committee.	Based on a relatively constant projected oil price of 100$ per barrel through to 2030, future oil-indexed LNG contracts at prices of 10-15$/ mmBTU (1mmBTU=293kWh) have been used in a range of studies assessing the costs and benefits of LNG as a shipping fuel[2].
Ocean Shipping consultants (*Royal Haskoning*), LNG as a bunker fuel: future demand prospects & port design options (2013).	A Danish Maritime Authority study[3] focusing on Northern Europe estimated future LNG prices in comparison to MGO price forecasts. The results of the analysis stated that LNG prices will be within the range 60-80% of the HFO price on energy basis.

Source: OECD, IEA, EIA

Table 5 Increasing rates on daily operating costs per type of vessel.

Type of vessel	Increasing range(%) [1.2 P_{HFO} – 2.0 P_{HFO}]	Type of vessel	Increasing range (%) [1.2 P_{HFO} – 2.0 P_{HFO}]
Container vessels	[15-75%]	Tankers	[15-60%]
Conventional dry cargo vessels	[13-65%]	Ro-Ro vessels	[10-50%]
Dry bulk vessels	[13-65%]	Car and passenger ferries	[11-55%]

Source: Finnish study and own elaboration

3 VESSELS´ OPERATING COSTS

It should be noticed that not all types of vessels will be similarly affected by the increased bunkering prices. It depends on the share of bunker costs on vessel's voyage operating cost and on the route concerned.

According to the COMPASS study and price costs in 2005, bunker costs represents on average 47% of the daily operating costs for a container vessel, 32% for a Ro-Ro vessel, and 22 and 12% for large and small RoPax vessels, respectively. The total daily cost included manning, insurance, repairs and maintenance, stores and lube oils, administration, capital investments, interests, bunkering costs and port fees. Nevertheless, it should be considered that fuel consumption is very sensitive to the vessel speed. In fact, the relationship between fuel consumption and vessel speed follows a logarithmic function.

In such a context, a Finnish study[4] estimated the effect of the estimated price rise for fuel on the day-to-day running costs for container vessels. For container vessels the bunker costs share is about 75%; 65% for conventional dry cargo vessels; 65% for dry bulk vessels; 60% for tanker vessels; 50% for Ro-Ro vessels and 55% for car and passenger ferries.

4 IMPACTS ON OPERATING COSTS

Thus, the increasing range on daily operating cost can be estimated according to the following expression: $S(\%)(P_{LSMGO}/P_{HFO} - 1)$; where S (%) is bunker cost share per type of vessel. Table 5 shows increasing ranges when the price of LSMGO ranges from 1.2 to 2.0 in comparison to the price of conventional fuel HFO.

5 USING LNG AS FUEL FOR NON-METHANE CARRIER SHIPS

Using LNG as fuel for non methane carrier ships is one of the most used alternative to traditional fuel oils.

Payback time for a LNG fuelled ship is attractive from a price differential between LNG and oil of about 15%. Oil price reduction on 2015 at about one half than last year has made difficult to justify its use.

In Figure 4 is the forecast for the evolution of different fuel's price. HFO is Heavy Fuel Oil, LSHF is Low Sulfur Heavy Fuel, MGO is Marine Gas Oil and LNG Is Liquefied Natural Gas. The current HFO prices in the

2 World Ports Climate Initiative (WPCI). IAPH – Port Environment Commitee. (http://www.lngbunkering.org/lng/business-case/incentives)

3 Ocean Shipping consultants (Royal Haskoning), LNG as a bunker fuel: future demand prospects & port design options (2013).

4 Ministry of Transport and Communications Finland (2009). Sulphur content in ships bunker fuel in 2015. A study on the impacts of the new IMO regulations on transportation costs.

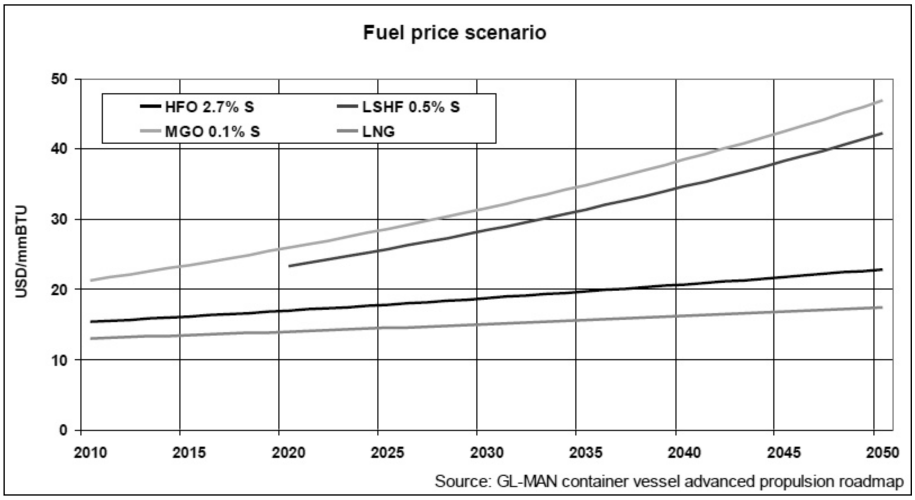


Figure 4 Fuel price scenario
Source: GL-MAN *Costs and Benefits of LNG as Ship Fuel for Container Vessels.* MAN Diesel & Turbo, 2012

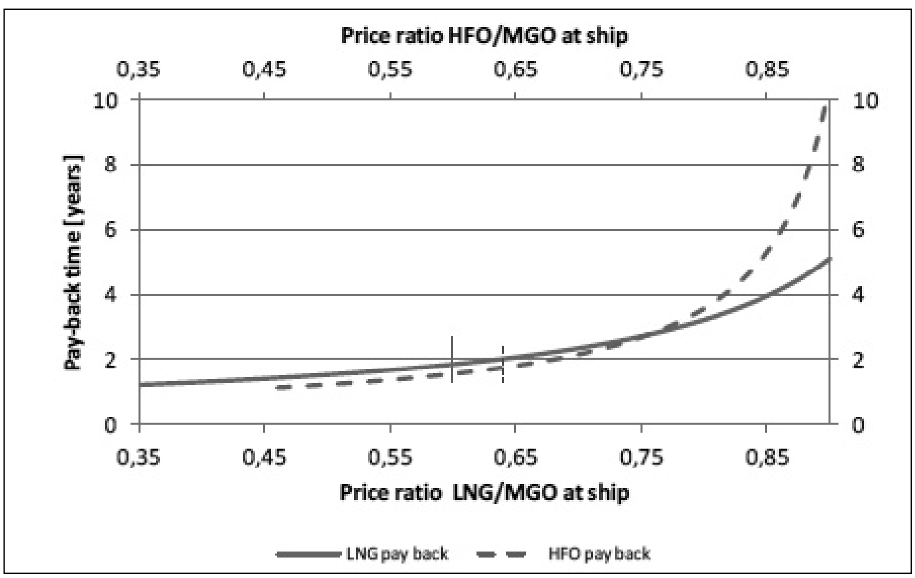


Figure 5 Payback time for different fuel prices
Source: Danish Maritime Authority

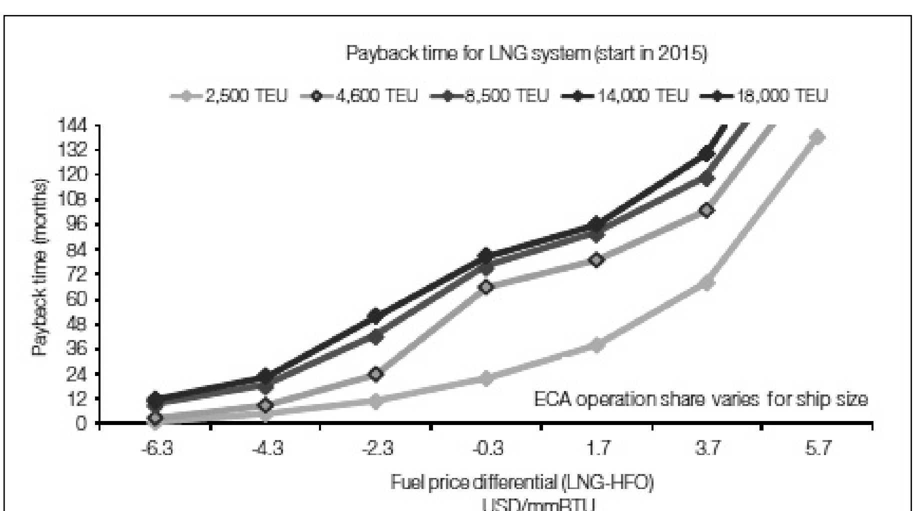


Figure 6 Payback time for LNG system
Source: GL-MAN *Costs and Benefits of LNG as Ship Fuel for Container Vessels.* MAN Diesel & Turbo, 2012

first half of 2015 are below this value but this may be a transitorial exception.

In Figure 5 is the payback time for different fuel prices. It is shown for the relationship between HFO and MGO and also for the relationship between LNG and MGO.

It is very important the percentage of time that the ship is sailing in ECAs where lower emissions are allowed.

In figure 6 is the payback time for different ship sizes each with different ECA operation share.

6 SAFETY OF EQUIPMENTS AND OPERATIONS OF LNG

Safety must be ensured in the whole ship during all operations, when fueling or sailing. All gas piping should be double pipes with nitrogen or circulating air between both and with gas detectors. Air renovations in the engine room should be high enough using extractors and fans, up to thirty air changes for hour, though this may render difficult gas leaking detection.

Gas compressors should be placed in a room out of the engine room and some propose that it should be two gas compressor rooms separated tightly.

The gas supply system should be duplicated in order to avoid stop of engines or black out if there is some problem in this system. Gas Combustion Unit (GCU) should not be duplicated.

7 STORAGE ON BOARD OF LNG

LNG has a density about one half of traditional fuel oils and it is more difficult to optimize cargo and fuel spaces. In addition, tanks must be isolated due to the cryogenic temperatures of LNG. Then, the overall volume occupied for all LNG facilities on board is between 2.5 and 4 times higher than for conventional fuels, which represents a significant loss of cargo space for most types of ships.

IMO A, B, C and membrane tanks are used. Membrane tanks have the advantage to adapt well to the ship spaces though tanks type C can withstand Boil Off Gas (BOG) pressure. This allows storage of BOG for up to two weeks. Insulation is usually a combination of vacuum, perlite or polyurethane. Tanks and tanks compartment need special ventilation and tank vent piping to raised vent mast on deck,

8 BASIC TYPES OG LNG ENGINES

There are three basic types of LNG engines:

1. Lean burn, spark-ignition, pure gas types, operate on the Otto cycle and use a spark plug to ignite the gas/air mixture in the combustion chamber, they range in power from 300 kW to 10000 kW.
2. Dual fuel with Diesel pilot engines operate on the Otto cycle and use 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. They range in power from 700 kW to 18,000 kW.
3. Direct injection with diesel pilot engines operate 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. Gas must be injected at high pressure. At present, no medium- or high-speed marine engines are available in this category, but slow-speed engines now on order can deliver up to 42,700 kW.

9 ADVANTAGES OF LNG

Fulfillment of environmental laws and norms regarding SOx, NOx, PM, and less CO_2 emissions though there is an increase of methane emissions due to the crossing of engine valves.

10 DRAWBACKS OF LNG

Not all harbors have facilities to supply LNG to ships.

A stress analysis for LNG piping following ASME 13B1.3 is required taking account of the dilatations and contractions of piping, and other additional forces as wind, snow or ice or strain produced by the hogging and sagging of the hull.

When the ship is anchored or in port or sailing very slow, it may be produced more BOG than the fuel consumed by the engines and then not necessary gas must be burned in a boiler or in the GCU.

Challenges for future development:

- Develop tanks and systems able to manage BOG and adaptable to the hull's shape.
- Modify the engines in order to avoid methane emissions due to valve crossing.
- Ensure the supply of LNG in all ports.

11 BIOFUELS

Biofuels can be derived from three primary sources: edible crops, non-edible crops (waste, or crops harvested on marginal land) and algae, which can grow on water and does not compete with food production.

Algae-based biofuels seem to be the most efficient and the process has the added benefit of consuming significant quantities of CO_2, but more research is needed to be done to identify alga strains that would be suitable for efficient large scale production. Concerns related to long-term storage stability of biofuels on board ships, and issues with corrosion are also necessary.

All biofuels can be mixed with traditional fuels. Besides the lower GHG emissions they can biodegrade rapidly and thus is less noxious in case of a spill.

Another biofuel is Bio-LNG:

- Bio-LNG is produced from biogas. Biogas is produced by anaerobic digestion. All organic waste can rot and can produce biogas, the bacteria do the work. Therefore biogas is the cheapest and cleanest biofuel without competition with food or land use.
- Biogas is produced from organic waste, sewage sludge, agricultural waste and landfills by anaerobic fermentation. The aim is to produce constant flow of biogas with consistently high methane content. The biogas must be upgraded: removal of H_2S, CO_2 and trace elements. The bio-methane must be purified (maximum 50ppm CO_2, no water) to prepare for liquefaction.
- Bio-LNG is of better quality than fossil LNG. The bacteria do not produce ethane, propane and butane. Therefore Bio-LNG has a higher methane number than (most) fossil LNG, which is important for engine performance and efficiency.
- Bio-LNG has a much lower carbon footprint than other fossil fuels or even many other biofuels: Bio-LNG can even be carbon negative.
- Anglo Dutch Liquid Methane BV estimates that bio-LNG can replace 20% of our fossil transportation fuels by 2020 in inland navigation, heavy duty trucks and cold ironing in ports.

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