LNG AS A MARINE FUEL – POSSIBILITIES AND PROBLEMS

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Abstract

The limitations of marine fuels use incorporated sulphur on levels 4-5% for HFO and 0.5-1% for MDO were caused a necessity of possessing on ship a few types of fuel: conventional and with limited amount of sulphur. It is a necessary to separate the installation of different fuels caused that the ship fuel system are complicated. It is needed to change the fuel with time advance on areas with SO_x controlled emissions (SECA areas) for example Baltic and North Sea. In the same time it is needed to change the engine adjustment in the aim of decreasing NO_x emission. It allows for fulfilling the emission on tier 2 level (IMO regulations). It was announced for January 1st, 2016 the time of tier 3 requirement of being in force. It is seemed to be impossible the fulfilling of that standard on marine liquid fuels (HFO and MDO). It was interested on gas fuels, especially on popular one the liquid natural gas (LNG). In the liquid state LNG is seemed to be an attractive marine fuel. It is remaining a problem of marine engines adaptation for burning that type of fuel in the aim of fulfilling the tier3 standard. At present, available dual fuel for marine diesel engines burn natural gas for ship operating reasons. Fulfilment these requirements needs an engine modernization or the alternative way is use of piston spark engines. There is an additional problem the assurance of repeatability of natural gas combustion process. During the change of engine load changes the fuel-air mixture composition, it is heterogeneous in the cylinder volume caused the ignition loss, the knocking combustion and the risk of out-of-control fuel self-ignition. The paper presents a probe of analysis these problems.

Keywords: *marine fuel, LNG, ship propulsion*

1. Initial remarks

Liquefied natural gas (LNG) has served as a marine fuel for many years, but primarily on LNG carriers as “the boil off” gas. It was utilized in marine boilers or dual fuel engines. It is only within last decade that the growth of LNG-fuelled vessel market has really taken in Europe. The growth of mentioned market is mainly due to the strict environmental regulations in coastal areas. Given that onshore industries have been cutting emissions, ship emissions are becoming a proportionally more significant part of total emissions. It is estimated that shipping emissions account for 2-4% of CO_2 global emissions, 10-20% of global NO_x emissions and 4-8% of global SO_x emissions [12].

According to limitation of NO_x emission MARPOL Annex VI, Regulation 13 the effective date IMO tiers are as follows:

- Tier 1 (current limits for new engines):
  - for engines on board ships constructed from 1st January 2000 till 31st December 2010; target for retrofit of existing engines (power over 5 MW) and displacement per cylinder over 90 dm^3 for ships constructed from 1st January 1990 but prior 1st January, 2000,
- Tier 2 (level about 20% below Tier 1):
  - engines on board ships constructed from 1st January, 2011,
- Tier 3 (level 80% below Tier 1) only in ECA’s:
  - engines on board ships constructed from 1st January, 2016, if combined propulsion power is over 750 kW.

Implementation schedule for MARPOL Annex VI was presented on Fig. 1.

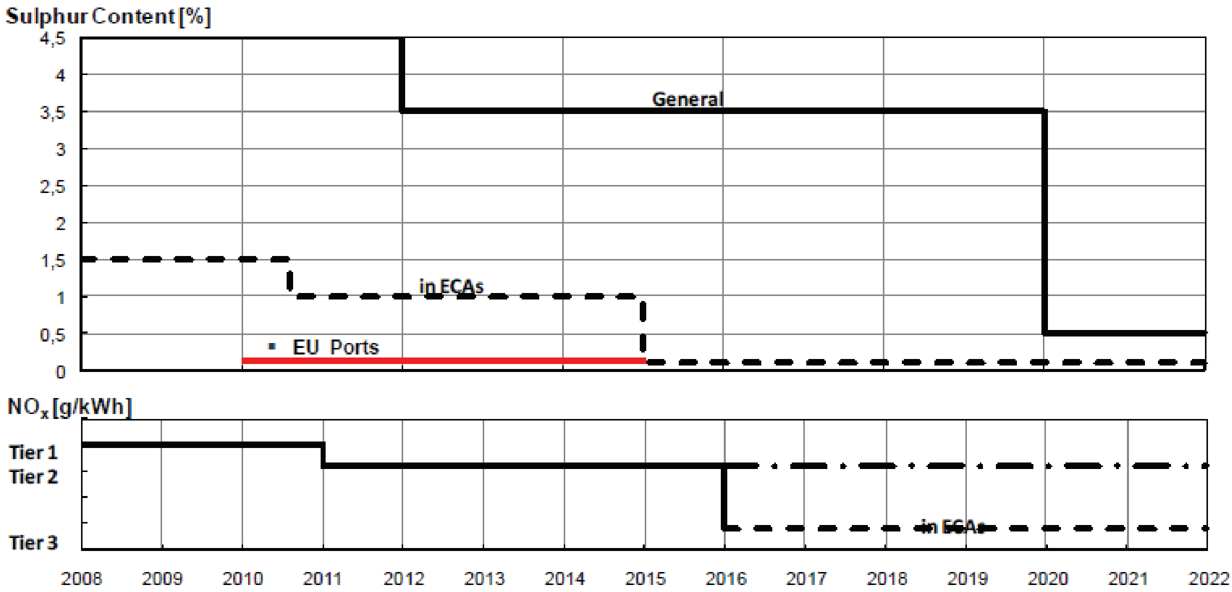

Fig. 1. Implementation schedule for Revised MARPOL Annex VI [9]

After 2015 tier 2 will be obligatory on all areas, tier 3 only on ECA's and tier4 on onshore installations [14]. Compared to the high sulphur residual fuels most widely used at present, LNG is said to reduce carbon dioxide (CO_2) emissions by around 20%, nitrogen oxides (NO_x) by 85-90% and gives a near 100% reduction in sulphur oxides (SO_x) and particle emissions. LNG can meet the stringent emission standards, including tier 3 NO_x limits and SO_x requirements on ECA's, without any treatment of the exhaust gas [13]. DNV (det Norske Veritas) has said that there are "three main solutions" for emission control areas (ECA's) compliance after 2015 when the sulphur content falls to 0.1%: low sulphur fuels, scrubbers for exhaust gas purification or the ships ought to be fuelled by LNG. The use of LNG as a potential replacement for conventional bunker fuels has become an increasingly discussed within the shipping industry. While LNG has many merits, there are also challenges (technical problems) which the shipping sector has to be confronted. The most important one is seemed to be LNG market: lack of much usable supply chain for distributing the fuel.

2. Important parameters of LNG as a marine fuel

LNG is colourless and odourless flammable gas ignitable by static electricity. Extremely cold and volatile liquid. Vapour forms highly flammable mixtures with air which may cause flash fire. The boiling point is -161.5°C at normal conditions. The flash point is -187.8°C, but auto-ignition temperature is 537°C. Flammable limits by volume: LEL 5% UEL 15% (with a little change depends on gas composition). The specific gravity of liquid is 0.45 and 0.6 of gas [1, 2]. Compressed natural gas (CNG) to 25 MPa has density 185 kg/m^3. Liquefaction makes possible to increase density to 460 kg/m^3. The LHV average about 46-50.2 MJ/kg. The burning speed in stoichiometric mixture is 0.38 m/s. It is too slow for use only LNG as a fuel in diesel engines.

By comparison to heavy fuel oils (HFO) tanks, LNG tanks ought to be about 2.5 times bigger by reason of smaller density and needed thermal shield [10]. Proposals of localization of LNG fuel tanks were presented on Fig. 2.

The bigger needed volume of LNG fuel tanks is a one of disadvantage of LNG use. The localization of LNG fuel tanks can take into account the ship safety.

LNG vapour is lighter than air. If LNG spills on the ground or on water and the resulting flammable mixture of vapour and air does not encounter an ignition source, it will warm, rise and

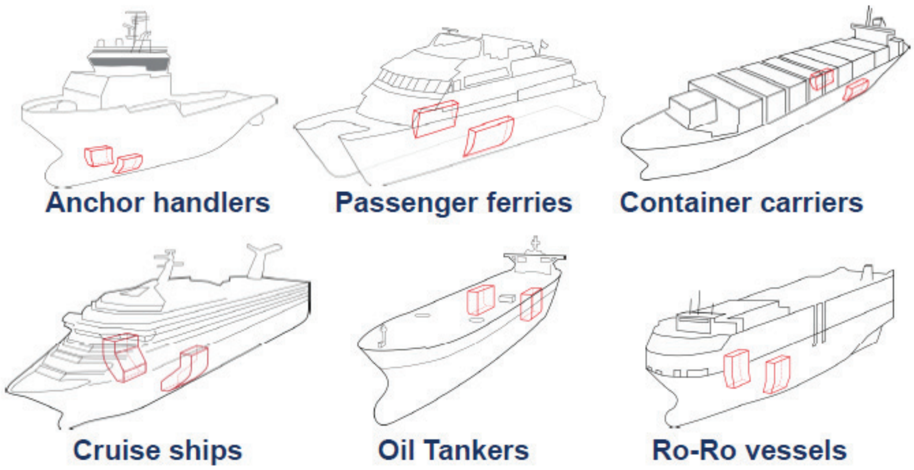

Fig. 2. Proposals of LNG storage tanks [11]

dissipate into the atmosphere. Because of these properties, the potential hazards associated with LNG include heat from ignited LNG vapours and direct exposure of skin or equipment to a cryogenic (extremely cold) substance. There is a very low probability of release of LNG during normal ship operations due to the safety systems that are in place. Unexpected large releases of LNG, such as might be associated with acts of terrorism or piracy, bear special consideration although the consequences may well be similar to a catastrophic failure. Since LNG is stored at atmospheric pressure – not pressurized – a crack or puncture of the container will not create an immediate explosion.

When released on water, LNG floats – being less dense than water – and vaporizes. If large volumes of LNG are released on water, it may vaporize too quickly causing a rapid phase transition (RPT). Water temperature and the presence of substances other than methane also affect the likelihood of an LNG. An RPT can only occur if there is mixing between the LNG and water. RPTs range from small pops to large blasts enough to potentially damage light weight structures. Other liquids with widely differing temperatures and boiling points can create similar incidents when they come in contact with each other.

3. Possibilities of use LNG as a marine fuel

As it was above mentioned LNG is a marine fuel for about fifty years. Till 2000 it was only utilization process of LNG vaporization (boil-off) from cargo tanks. At present it may be a marine fuel and replace the heavy fuel oils. There is no problem to prepare the gas turbines and boilers (for steam turbines) for burning natural gas. It affects continuous combustion – this is an advantage for these engines.

By reason of efficiency it may mainly try to use LNG as a marine fuel in diesel engines – two and four stroke. The propositions are dual fuel (DF) or three fuel (TF) engines. The engines may work on heavy fuel oils, if necessary on marine diesel oils (during manoeuvres or low loads) and of course on natural gas. There are self-ignition diesel engines. In the case the two stroke diesel engine works on natural gas it is needed to inject a pilot dose of liquid fuel (more often 1% of marine diesel oil) for the facilitation of self-ignition the fuel-air mixture. The natural gas is injected to the cylinder under pressure about 25-35 MPa (it is a problem to use high pressure compressors). In the case the four stroke diesel engines the natural gas is passing to the air inlet channel under pressure about 0.5-0.6 MPa (more convenient pressure). The pilot dose of MDO or HFO is needed too. The dual fuel engines are not sensitive to gas quality and the load (Fig. 3).

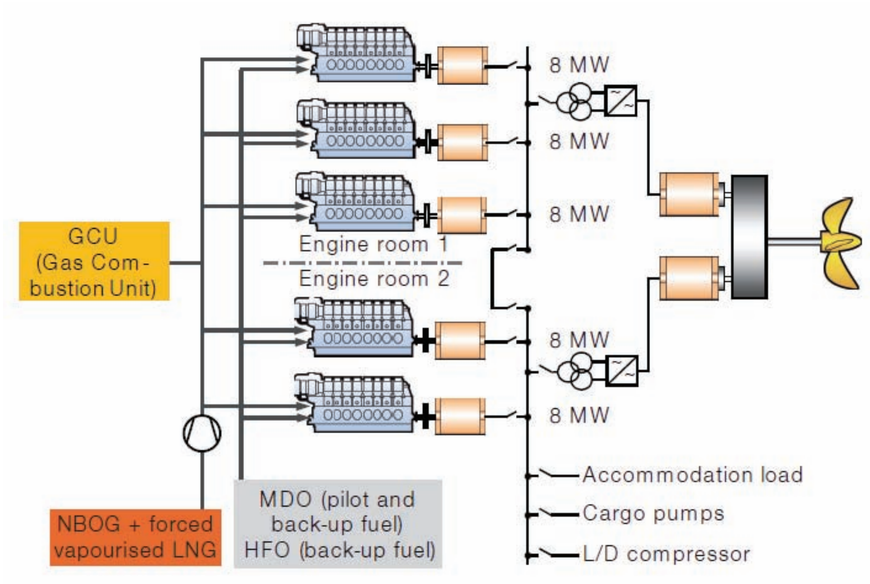

Fig. 3. Schematic main machinery of a four stroke dual fuel diesel engine plant incorporating total fuel flexibility with any possible ratio of liquid fuel (MDO or HFO) and gas [16]

The thermodynamic cycle of engine work is Sabathe-Seiliger's cycle independently on used fuel. Even in the case of delayed injection (for the restriction of NO_x emissions) the engines may produce the NO_x emissions below the level of tier 2, but it is impossible to fulfil the level of tier 3 (see Fig. 1) without the purification exhaust gases process [3, 4]. It is needed SCR (selective catalytic reactor) for NO_x reduction to meet IMO tier 3 [5]. It will be possible if the engines work on Otto's thermodynamic cycle. It means that the engines ought to be the spark ignition engines, not used in marine industry before year 2000. It is obligatory to build another type of engines. Here we meet a problem with the fulfilment of low NO_x emissions with correct and efficient work of spark engines (Fig. 4).

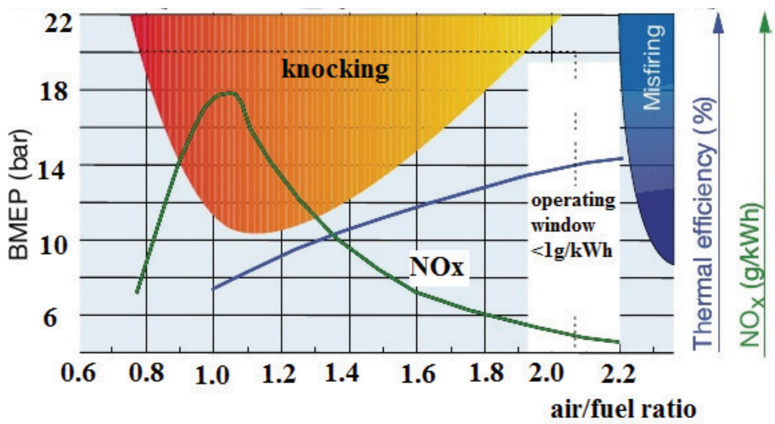

Fig. 4. Engine operating parameters and exhaust emissions as a function of excess air number [8]

The problem is increasing when the load of the spark engine is changing. The operating window (Fig. 3) is very narrow and the knocking area is jointing with misfiring area during great engine loads about 2.2-2.4 MPa of mean effective pressure (BMEP). It happens the misfiring cycles or knocking cycles (by reason of the fuel self-ignition in the other moments of thermodynamic cycle). It disturbs the correct work of engine, resulting in the increasing loads of all engine mechanisms and being the reason of quick engine malfunction or damage. The problem has been tried to solve by many marine engine manufacturers. At first it was tried to intensify the power of the spark by conventional spark plug, the next was tried the laser ignition (Fig. 5).

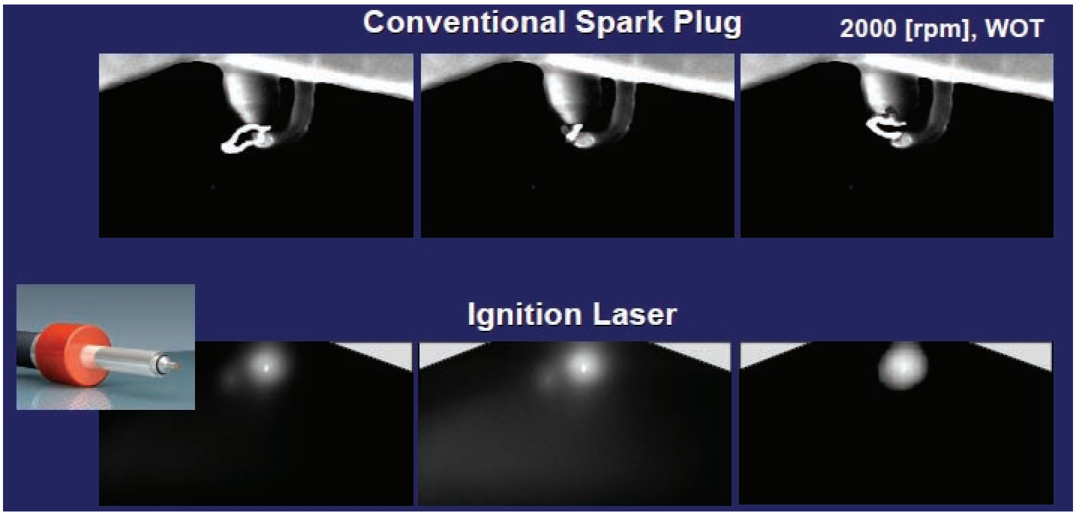

Fig. 5. Conventional and laser ignition [15]

The problem hasn't been solved properly till today. On the other hand it was become realized the probes for improving the fuel injection process. For example the Wartsila built in 2009 an experimental spray combustion chamber for testing the injection process (Fig. 6 and 7).

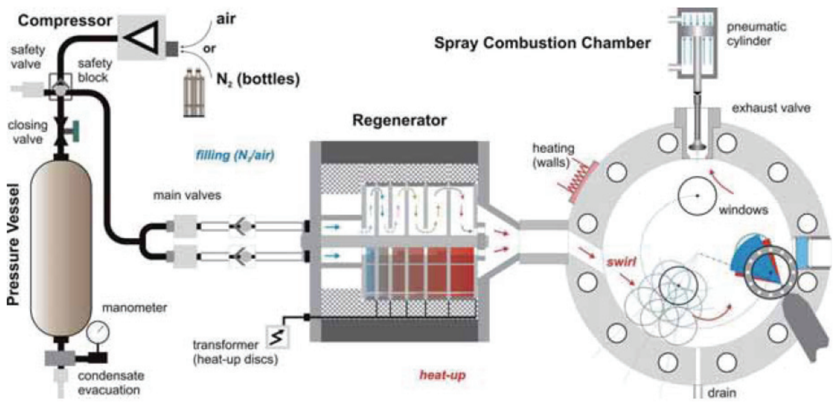

Fig. 6. Setup experimental SCC test facility [6]

The changing requirements resulting from recent developments in the marine industry (environmental regulations as well as fuel quality trends) make the more thorough optimization of combustion on large marine engines indispensible. For this purpose, appropriate tools are needed, both for supporting the development by means of sufficiently accurate simulations and for experimentally studying the effect of key parameters [6]. The spray combustion chamber takes a key role in this context – by providing reference data for the validation of simulation tools at relevant conditions and by allowing a direct verification of the effect of some design features.

4. Economical competitive LNG versus HFO

The price of LNG depends for many years on HFO price, but often is cheaper. Taken into account the LHV of fuels and theirs prices the cost of LNG is about 60% of HFO. On gas carriers the cost of boil-off gas is decreasing due to savings of reliquefaction process. Natural gas prices (including LNG) has been reduced the last two years due to the introduction of shale gas in the US market. This is a reason that LNG has improved its competitiveness to HFO, especially on ECA's areas where it is needed exhaust gas cleaning.

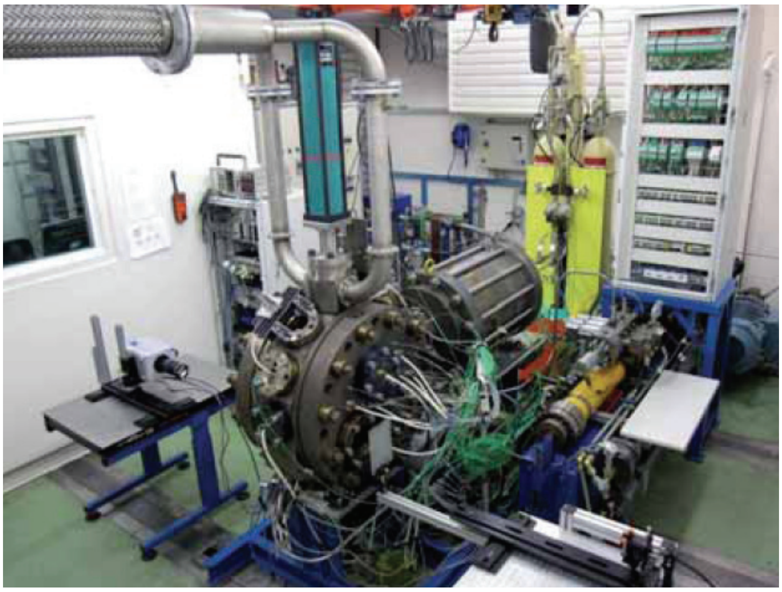

Fig. 7. Experimental setup of spray combustion chamber [6]

The basic question is what will be the price of HFO in the future. We must remember the middle of 2008 when the price of HFO IFO380 was over 1000 $ per metric ton. In the middle of 2011 is about 650 $ like in 2007 and first half-year 2008 (Fig. 8, Fig. 9.). It may be seen the increasing price of MDO and MGO fuels. Later the next step was the rise of HFO price. In my opinion the price of LNG will be more stable than HFO, because depends on the industry price.

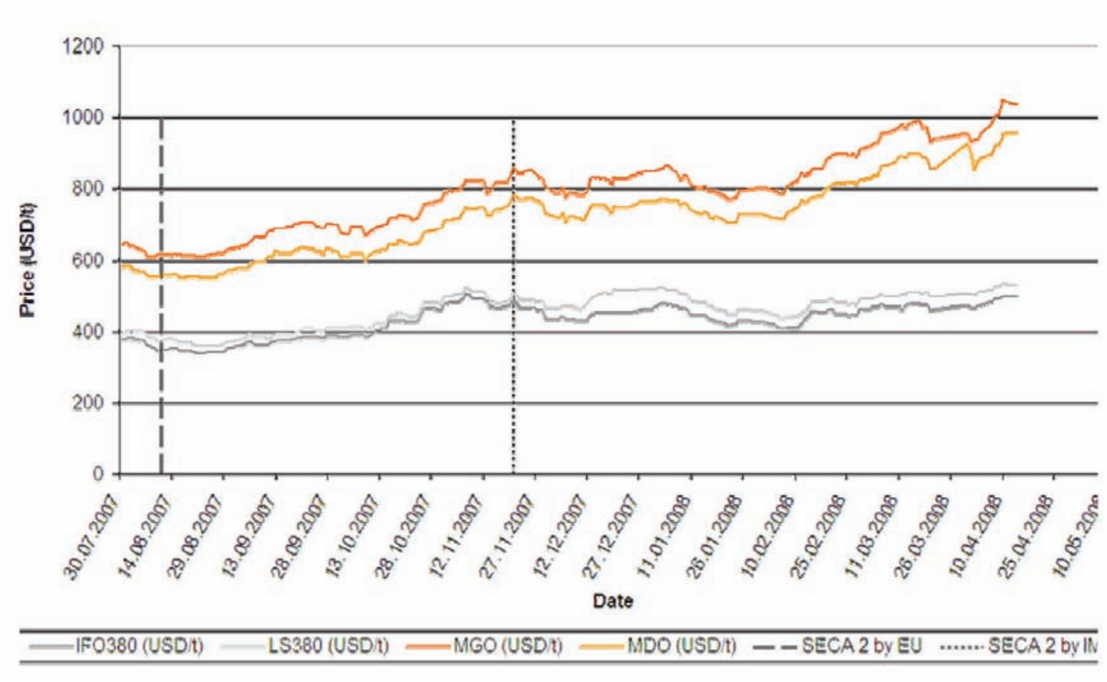

Fig. 8. Marine fuel price during one year 2007-2008 [13]

It must be remembered about LNG storage problems and cost of that and some needed safety equipment. On a long stay (due to the shipyard) the fuel tanks must be emptied because the fuel vaporization.

On the other hand LNG is very pure fuel. The operational costs of engines are decreasing. The engines are in the better technical states. The number of emergency situations and failures is decreasing. This is money too!

Fig. 9. Marine fuel price of IFO 380 during last year [www.bunkerworld.com]

In my opinion LNG will be competitive with HFO taking into account only price during the next 20 years, later it will be still better. Taking into account all other parameters the LNG competitiveness is better.

5. Final remarks

Several companies in the shipping industry, meanwhile, have revealed plans to develop gas-fuelled merchant ships. The reason is what to do now in the perspective of 2016 year and the IMO requirements. There is no problem with fulfilment the tier 3 by LNG as a fuel. LNG is available on the wide world. It is possible to built small barges for small scale distribution by dedicated ships is available, especially in ports where are existing LNG storage infrastructure. Storage technology for ships is available and needs further development. Gas engine technology for ships' main propulsion and gensets is available for all types of piston engines. For existing ships this is a problem how prepare them for tier 3. The engine replacing is only the one way, but expensive and not economical. The greater problem concerns ships on ECAs and SECAs areas.

LNG has the potential to be economical competitive to HFO. The future will show the real possibilities to replace HFO as a marine fuel on ships by gaseous fuels, especially LNG.

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