Natural Gas Propulsion
-The Greenest Way

Giulio Tirelli *

1. Importance of gas in the actual market

The history of Natural Gas (NG) extends to antiquity. In America it was already known to the Indians, who observed it issuing from the ground in various spots, and it was used for illuminating purposes in Fredonia, N.Y., as early as 1821.

Despite the early discover and utilization on small-scale, in the recent area, Natural Gas has always been considered as a by-product associated to petroleum research and extraction, being oxidized for decades at the well-site. Unwanted gas (also called ‘stranded gas’, without a market) represented a problem being its commercialization almost impossible. Liquid fossil extraction fields have traditionally been located far from any possible end user and the investments related to a possible gas-pipeline construction could have never been oﬀ-set by the inconsistent natural gas market price.

With an increasing world energy demand and being Natural Gas able to oﬀer high energy content combined with a short hydrocarbon chain, the importance of this source of energy started rising during the last few decades.

The Natural Gas trading always followed two paths, still valid during the present days and remained for long time on a parallel growing scale. The ﬁrst one is related to pipeline distribution: the gas is traded in its gaseous form, being transported via pressure increase and distributed up to pressure reduction station. From there, the pressure is then adjusted accordingly to the users’ needs. The second trading form is related to marine transportation: in order to increase the energy density and to transport the highest amount of gas, the NG is chilled down to around −160 °C, with a corresponding density increase of roughly six hundreds times. At this temperature the gas reaches its liquid phase and it is known as Liqueﬁed Natural Gas – LNG.

* Marketing & Application Development Manager
Wärtsilä – Ship Power

World pioneer in the use of LNG has been Japan followed closely by South Korea. Fifty years ago the LNG market was basically conﬁned into the Far East region with reliquefaction facilities installed in Malaysia and Indonesia and re-gasification infrastructures in Japan and South Korea.

From this primitive condition, the LNG market has been widening its horizons around the world and nowadays involves globally all countries and all relative transportation routes.

Proving the LNG growing importance is the statistical value of proven Natural Gas reserves, represented in Fig. 1, where 185, 02 trillion m$^3$ where registered at the end of 2008, with an increase of 69% compared to the value registered two decades before, 109,72 trillion m$^3$. The positive evolution of proven reserves is strictly linked to the exploration activity and interest of gas companies, able to understand the value of such a fossil fuel.

Associated with these ﬁgures, the Liqueﬁed Natural Gas Carrier (LNGC) ﬂeet evolution is represented in Fig. 2, showing how the marine market coped with an increasing demand for LNG. Historically, both the number of LNGCs sailing around the world and their cargo capacities have been constantly increasing.

Today the LNG trading market involves all continents in a complex demand-supply chain. Natural gas accounts for 24.1% of world energy use, the highest share on record.

Fig. 1: Evolution in Natural gas proven reserves during the last two decades.

Fig. 2: Evolution of LNGC fleet capacity.

Middle East
Europe and Eurasia
Asia Pacific
Africa
North America
South and Central America
2. Emission regulation evolutions: present and future requirements

The marine market is today asked to contribute to the worldwide strive for reducing the pollutant emission to the atmosphere. Rules have been developed around four major contaminating substances:

**Nitrogen Oxides**: usually referred as NOx, they react with ammonia, moisture, and other compounds to form nitric acid vapor and related particles. NOx are one of the key pollutants which cause acid rains and has direct effect on human health.

**Sulphur Oxides**: usually referred as SOx. Since coal and petroleum often contain sulphur compounds, their combustion generates sulphur oxides. Further oxidation of SO2, usually in the presence of a catalyst such as NO2, forms H2SO4, and thus acid rain.

**Carbon Dioxide**, CO2: it is one of the major responsible for the greenhouse effect, causing hearth temperature to rise.

**Particulate matter**: are tiny particles of solid or liquid produced by the fossil fuel combustion suspended in the air. They have a strong repercussion on human and animal health being responsible for several pathologies.

Currently, maximum NOx and SOx emissions levels from fossil fuels combustions are regulated in the marine market by the International Maritime Organization (IMO). Maximum allowable NOx emission limits are divided in three consecutive implementation steps, commonly know as IMO Tier I (actually in force), Tier II (coming into force in 2011) and Tier III (coming into force in 2016, only in designated areas). The average NOx production coming from marine reciprocating engines should be calculated in accordance with rules set by the same IMO and should not exceed the limit as reported in Fig. 3.

SOx emissions are controlled reducing the sulphur content concentration in the fuels bunkered onboard. The existing regulations and future developments are represented in Fig. 4.

As a general approach it appears clear that the tendency is to restrict worldwide pollutant production especially in harbours or close to urban areas. In this optic, regulations on CO2 and particulate matter production are to be expected in the upcoming future.

3. Natural Gas application on vessels powered by Wärtsilä Dual-Fuel Engines

Natural Gas is a gas consisting primarily of methane, CH4, with energy content close to 50 MJ/kg (depending on specific gas composition), remarkably higher than common liquid fuels available on the marine market. Natural Gas’ hydrogen to carbon ratio is close to the pure methane one, 4:1, thus being the highest among all hydrocarbons.

The advantages of using such an energy source as marine fuel should be combined with ensuring a continuous and safe vessel’s operation.

Wärtsilä Dual-fuel (DF) engines are reciprocating marine
prime movers studied and optimized for operating on gas mode thus utilizing natural gas a primary source of energy. When a DF engine is in gas mode, it operates according to the Otto principle. The gas is mixed with air and admitted to the combustion space during the expansion stroke. A low gas admission pressure of some five Bar is sufficient. At the end of the compression stroke, a small quantity of Marine Diesel Oil (MDO) is injected into the combustion space to trigger a stable and complete combustion of the gas and air mixture (Fig. 5). The injected MDO is called the *pilot fuel*. Dual-fuel technology is only available on four-stroke engines.

In diesel mode, Dual-fuel engines act like normal diesel engines, with the gas admission ceased and the pilot fuel injection complemented by the injection of additional HFO or MDO (Fig. 6). One single lubricating oil can be selected for operation in gas mode and diesel mode.

In case the engine is running in gas mode and the supply of gas is interrupted or an alarm situation occurs, it automatically and instantly trips to diesel mode, without loss of engine power and speed. Transfers from gas mode to diesel mode can also be carried out on demand, at any load, and again without loss of engine power and speed.

More than one thousand Dual-fuel engines are today in commercial operation or are foreseen to start their activity in the next two years. The success of this technology in the marine world is due to the combination of the following advantages:

**Environment:** Wärtsilä Dual-Fuel engines in gas mode reach an efficiency of roughly forty eight percent, definitely higher than whichever other four-stroke engine. Being the engine so efficient, the amount of fuel utilized per unit of energy produced is lower than on a normal diesel engine and the related emissions are following the same path. Basically: the more efficient the solution, the smaller the amount of fuel to be utilized and the smaller the amount of pollutants produced.

In addition to this consideration, NOx are further reduced thanks to “lean-burn” combustion principle, SOx are basically not existent as far as the natural gas is not containing any sulphur, CO2 are reduced thanks to the high hydrogen to carbon ratio and particulate matter are substantially completely absent.

In Fig. 7 is represented a comparison between different emission levels of a common marine diesel engine running on MDO (assumed containing 1% sulphur) and a DF engine running on natural gas.

**Economy:** natural gas price has historically been always lower than the other fossil liquid marine fuels. In addition to that, the Dual-fuel technology permits to reselect the most advantageous fuel every time it is required or desired. This feature detaches the operator from fluctuation on fuel bunkering price and possible market volatility.

**Reliability and redundancy:** Dual-fuel engines have inherited reliability from the diesel engine models from which they have been derived. The use of a clean fuel and a lower cylinder output on the dual-fuel engine models further enhances their reliability.

On pure gas, spark ignited engines installations, in case of any failure in the gas supply system, the main engines are forced to be shut down missing the only fuel they are able to burn. A certain level of redundancy can be ensured by installing additional diesel engines which will have then to be started. This solution appears, in any case, against any engineering principle: it increases the total vessel’s total installed power, requires useless waste of space and weight and reduces vessel cargo capacity. Feature of Dual-fuel engine installations is that the engines could always instantly changeover to liquid fuel mode without any loss of output or engine speed, ensuring a continuous, safe and reliable operation.
Natural Gas Propulsion - The Greenest Way

Journal of the JIME Vol. 44, No. 6 (2009)

Fig. 7: Emission comparison between a diesel engine running on MDO and a dual-fuel engine running on gas.

4. Compliancy with emission regulations: possible solutions

When selecting the equipment to be installed onboard a vessel, usually a decision between several different alternatives should be taken. The main purpose of this article is to focus on the possible ways to achieve a significant reduction on emission levels, making the installation compliant with the upcoming regulations as previously described.

The technology actually available on the market reduces the available alternatives to three, based on the fuel typology utilized as source of energy.

1. Low Sulphur Fuel Oil (LSFO): utilizing a liquid fuel with low sulphur concentration will make possible to comply with SOx emissions regulations. NOx levels, as defined by IMO Tier III limit curve, would not be achieved simply with engine modification and installing a Selective Catalytic Reduction (SCR) in the exhaust pipes will become necessary.

Questions rise on the future large scale availability of such a LSFO, on its physical properties, on the refineries’ interest to produce it and on its end-user price.

2. Heavy Fuel Oil (HFO): it represents the actual standard as marine fuel oil. In case this liquid fossil fuel continues being the main source of energy onboard a vessel, both an SCR and an Exhaust Scrubber should be installed onboard. This in order to reduce both NOx and SOx concentration in exhaust gases down to the required levels.

3. Liquefied Natural Gas (LNG): burning gas as marine fuel elegantly solves the emission compliancy issue, fulfilling simultaneously the requirements related to both SOx and NOx. No additional emission abatement technology is required as in the previous two cases.

It should be said that only gas in its liquid form could be considered as a valid alternative to LSFO or HFO. Natural gas stored in gaseous form seems not a valuable alternative: the amount of natural gas required to cover the vessel’s power requirements would occupy such a huge volume that the whole installation will become not feasible. Possible applications of Compressed Natural Gas (CNG) could see the light in the coming future but they will be reduced to very few specific projects and, therefore, are currently not taken into account in this essay.

Fig. 8 shows a schematic summary of the possibilities just presented.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>SOx requirements</th>
<th>NOx requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Sulphur Fuel Oil (LSFO)</td>
<td>Compliant</td>
<td>Not compliant SCR needed!</td>
</tr>
<tr>
<td>Heavy Fuel Oil (HFO)</td>
<td>Not compliant</td>
<td>Scrubber needed!</td>
</tr>
<tr>
<td>Liquefied Natural Gas (LNG)</td>
<td>Compliant</td>
<td>Compliant</td>
</tr>
</tbody>
</table>

Fig. 8: Alternative solutions for emission regulation compliancy.

5. Onboard installation and economical impact of different alternatives

All three cases presented in the previous chapter will have an impact on both vessels’ price and vessels’ operating costs. Capital Expenditure (CapEx) and Operational Expenditure (OpEx) should be evaluated in detail on a case-by-case basis but some general principles and considerations are valid for all installations.

In case an SCR should be installed onboard (common to both the LSFO and the HFO cases), the vessel economical feasibility will be affected by the SCR unit cost, by the urea tank and dosing unit cost and by the loss in space and weight related to this equipment. In addition, Urea consumption (typically around 20l/MWh) will be added to the vessel’s OpEx and its price is usually significant. In Fig 9 is represented an SCR installation outline.

When installing an Exhaust Scrubber (valid for the HFO case), the following components should be considered: the Exhaust Scrubber unit to be placed in the exhaust stack is, clearly, the first in order of importance, size and cost. On the other hand it should not be forgotten that the onboard fresh water plant capacity should be dimensioned considering the
additional demand coming from the scrubber unit, which could be definitely consistent. For completing the chemical reaction, caustic soda is required and its consumption cost, as well as its dosing unit’s one, should be added. An example of Exhaust Scrubber installation is represented in Fig 10.

![Fig.9: Example of SCR installation](image1)

![Fig.10: Example of Scrubber installation](image2)

Finally, quite a relevant amount of space should be reserved onboard as water holding tank, where the contaminated water is stored before being discharged to shore during a port call.

The propulsion solution based on LNG requires neither the SCR nor the Scrubber systems: emissions regulations are fulfilled simply utilizing LNG as main source of power. On the other hand an LNG storage tank should be placed onboard: its cost, volume requirements and position onboard should be carefully evaluated for matching the most profitable solution while respecting vessel’s operational requirements and safety standards. Fig. 11 and 12 show two possible alternatives of LNG tank installation onboard a Ro-Pax: in the first the holding tanks are placed below deck while in the second the same tanks are installed on top of the main deck. The latter alternative has the main advantage of having the LNG directly stored in an open-air location, thus reducing the requirements for ventilation, needed in case the gas is stored in a confined space. The drawback of this solution consists in having a relatively big mass placed at a high level which will require a vessel’s stability assessment.

![Fig.11 & 12: LNG storage alternatives below and above deck.](image3)

6. LNG as marine fuels: applications

The marine applications of LNG as fuel are today mainly related to Norwegian owners and operators. The Scandinavians have been the first in producing infrastructures and developing a positive mindset towards gas propulsion in the marine environment. Presently, several different Ferries and Off-shore Supply Vessels are powered by engines running on gas.

The feasibility of several additional different applications based on LNG propulsion has been demonstrated through related studies.

A stopper in the further development of gas applications is today represented by the lack of available bunkering
facilities. Both public authorities and private companies are moving towards overcoming this issue producing and operating LNG on-shore infrastructures where the gas could be bunkered. In the meantime, the first applications foreseen to be powered by LNG would be fixed-line cruisers or coastal vessels for which the supply of fuel is ensured by a defined port call where the LNG bunkering facilities are already available. In this sense, Ro-Ro, Ro-Pax, Ferries and Tugs could represent the first marine section to undergo this evolution process towards greener propulsion. Additionally, these vessels are usually operating close to urban areas, with direct impact on local pollution.

Cruise ships and container feeders could follow closely this path, frequently sailing in emission sensitive areas. For passenger’s vessels, a greener solution could produce also a favorable image attracting the public and ending in being a driver towards the LNG propulsion selection.

Wärtsilä vessel designs developed for the Tug and Container Feeder applications are presented in Fig 13 and 14.

Three alternatives have been considered suitable in order to fulfill the current and upcoming emissions regulations standards in the marine market, divided on a fuel-typology base.

In case of LSFO or HFO utilization, additional equipment (SCR and Exhaust Scrubber) should be installed onboard, with the related negative impact on both CapEx and OpEx. Vice versa, if LNG is employed as main energy source, emissions regulations are fulfilled without any extra cost related to emission abatement technology. Only the expenses related to the LNG storage tank should be included when considering this alternative. Furthermore, OpEx will improve thanks to a lower gas price compared to liquid fuels, a detachment from market volatility and a beneficial impact on onboard maintenance.

Dual-fuel engines running in gas mode give the operators the advantages of being able to utilize the LNG as fuel always with its consequential benefits. Furthermore the vessel can always rely on possible switchover to liquid fuel mode, ensuring continuously safe and reliable operations.

References:

- BP Statistical Review of World Energy, June 2009
- “The efficient container feeder”, Wärtsilä internal development, January 2009
- “LNG concept for a Ro-Pax”, Wärtsilä internal development, April 2008

Author

- Tirelli Giulio
- Born in 1980 in Trieste, Italy
- M.Sc. in Naval Architecture at Trieste’s University
- Currently involved in gas propulsion and gas systems developments for marine applications