Passenger ships in the port of Piraeus in Greece.
he transportation sector is responsible for more than 25% of all oil products consumed worldwide and is the fastest growing sector in terms of oil demand. It is, therefore, also the fastest growing source of emissions. However, shipping is by far the most efficient and environmentally friendly means of transportation, accounting globally for 2.7% of worldwide CO₂ emissions and something in the region of 3% for total exhaust gas emissions.

The Greek shipping industry, and in particular the passenger fleet, is faced with several major issues that vitally affect its operation: the need to drastically decrease costs but at the same time to offer high-quality services to its passengers and respond to new emissions legislation.

As it now stands, liquefied natural gas (LNG) as potential fuel for the Greek ferry fleet is the most mature and viable solution, tackling on the one hand the strict emissions legislation and on the other hand the major task of reducing operational costs of vessels by lowering fuel costs.

Our focus here will be on the technical aspects for newbuildings and retrofits of LNG passenger ships, considering, among other things, the experience of the Northern European countries, which already run LNG fuelled ships. Emphasis will be given to retrofitting the existing fleet, which obviously is a more favorable solution with short-term results and which will positively affect local shipyards and ship repair capacity.

We also will examine the financial and operational aspects of LNG-fueled ships. Included will be a look at the existing infrastructure in the Piraeus vicinity, along with a methodology for estimating annual demand for LNG fuel, based on the types of ships and the number of calls in the port of Piraeus.

Already underway

In Europe, there are currently many projects underway for LNG terminals in ports as well as LNG-fueled ships. In Norway, passenger
ships are using LNG as fuel, and the first Finnish LNG passenger ship is a reality. We will examine indicative cost figures both for retrofitting and newbuildings with LNG. These figures will be compared with those of conventional ships using diesel fuel in which the necessary abatement techniques to comply with emissions legislation should be added.

Projects, still in the research stage, are also running in Greece, and Greek shipping companies are fostering the possibility of using LNG as fuel through retrofitting their existing fleet but also (in the medium to long term), through placing orders for newbuildings.

Forthcoming legislation for reducing the environmental footprint of the shipping industry has led ship owners, engine manufacturers, and ports to examine alternative clean energy sources and fuels. The International Maritime Organization (IMO) has legislated emissions from ships. Beginning in 2015 in emissions control areas (ECAs) and from 2020 onwards in other regions, the sulphur content of marine fuels will be drastically reduced.

LNG seems to be the most viable alternative solution to diesel fuel in terms of the environment and the economy. It is a proven technology, evidenced by the fact that approximately 40 ships are currently running on LNG. It meets emissions requirements and beyond, emits less CO₂ and most importantly it offers financial benefits in many cases. Nevertheless, a number of challenges still need to be overcome, especially when considering the application of LNG to the Greek passenger fleet.

At the Green Ship Technology Conference in 2011, more than 75% of the attendees expected LNG to be the fuel making the most progress within the next 10 years. And at Smart Shipping in Singapore that same year, 42% of public poll opinion respondents expected LNG to be the choice compliance fuel by 2025.

According to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, the general maximum limit of sulphur content of fuel, beginning in 2012, is 3.5% and 0.5% beginning in 2020. A more stringent limit is set for ECAs, namely 1% beginning in 2010 and 0.1% beginning in 2015. Alternatively, ships should install after-treatment cleaning systems or use other technologies to reduce their SOₓ emissions. These limits and the year of their implementation are shown in Figure 1.

It is under debate in the EU and it is certain that the new ECAs will include the Mediterranean Sea or at least parts of it. Furthermore, and according to an EU directive in force beginning January 1, 2010, all ships in EU ports with a port stay longer than 2 hours should use a fuel with sulphur content less than 0.1%.

Concerning the nitrogen oxides, the new IMO NOₓ Tier II rules became active in 2011 with a 20% limit below the 2010 emission levels. The next emission level, IMO Tier III, will be valid from 2016 onwards and is expected to demand an 80% reduction in NOₓ levels compared to Tier I.

**Age and numbers**

In addition to the fact that the Greek fleet is under reform pressure to upgrade the energy efficiency of its ships, the age and the decreasing numbers in the merchant fleet generally are seen as challenges. Consequently, passenger vessels (as a part of the fleet) also are exposed to the same upgrade/retrofit pressure. Relevant figures from the Hellenic Statistical Authority illustrate these tendencies: The Greek merchant fleet, for vessels of 100 GRT and over, decreased by 3.5% in June 2013 compared with June 2012. The fleet also recorded a decline of 2.7% in June 2012 compared with June 2011.

Focusing on the Greek passenger fleet, there are two main drivers for the adoption of LNG as fuel. First, LNG enables ships to meet IMO’s Annex VI for both cases, namely trading now in the Mediterranean, which is not an ECA area but also later on when it is more than probable that the Mediterranean will be designated an ECA. Second, it is expected that the price for LNG will be lower than for low-sulphur high-distillate marine diesel oil on a heating value basis.

On the technical side, the underlying fact is that LNG consists predominantly of methane (CH₄) that has been cooled to minus 160°C. At this temperature it is condensed into a colorless, odorless, non-corrosive and non-toxic liquid. In its liquefied form, it occupies 1/640th of its original volume, which enables ease of transportation and storage.

The use of LNG as a marine fuel is both ecological and cost effective. In Norway, it has been used for powering ferries for more than a decade. Since 2000, Norway has operated a number of LNG-powered passenger and RoPax ferries and currently there are at least eight passenger vessels in operation with others on order.
The technical requirements for a ship to burn LNG either as a newbuilding or as a modified existing vessel begin with an engine capable of using LNG as a fuel. Furthermore, the retrofit package includes special LNG tanks, a gas supply system, and a bunkering system, plus safety and control equipment. The engines used are divided into two main categories—gas only and pilot injected. Gas only units run solely on gas and the ignition of the air and gas mixture is achieved by a spark plug; in pilot injected engines, widely known as dual-fuel engines, a small injection of diesel fuel (approximately 1 to 1.5% of the normal fuel injection) is used to ignite the remainder of gas and air mixture. The dual-fuel engine can run either on LNG with the pilot ignition or it can switch back to diesel fuel and operate as a standard diesel engine. For the Greek passenger fleet, the dual-fuel engine is obviously the more flexible choice, because with the legislation on ECAs and fuel price development and deployment, it offers the possibility of using diesel oil, if this is considered more beneficial.

LNG storage tanks represent a critical technical issue especially in the RoPax vessel category. The LNG is maintained under pressure at minus 160°C in an insulated tank that is anticipated as a body of revolution; hence its location should be B/5 feet from the side of the vessel. For a ferry, and moreover for an existing one, the most suitable location for the tanks would surely be up on the sun deck to provide the B/5 clearance from the sides, but this also caters for any escaping vapor to dissipate naturally and not endanger vessel and passengers. For the dimensioning of the tanks, it should be kept in mind that LNG has approximately half of the density of diesel, and approximately 10% more heating value. The result is that the tank volume needed is approximately 165% more compared to diesel oil.

The vaporization of the LNG before leaving the tanks is accomplished by heat exchangers built in each of the tanks. In the engine room and before entering the engine, an LNG pipe goes through the gas regulating unit. The bunkering system must be carefully designed as ferries normally are tied up with the bow ramp on the pier; this means that access to the side of the vessel is possible only with a barge. A second option for bunkering is by truck with a hose connection being attached just inside the ramp to a manifold with the necessary valves for transfer to the LNG tank.

LNG contains less energy than diesel fuel. Approximately 1.67 liters of LNG is the equivalent of 1 liter of diesel oil, and this should be taken into account when calculating cost savings. Hence, the real saving per liter could be on the order of 50 to 60% given the extreme price fluctuation of the LNG market.

**Financial and feasibility issues**

Having examined critical issues from the operational/technical side of using LNG as fuel on a ship, we will now explore the financial feasibility considerations tailored to the Greek passenger fleet and to Piraeus as the main bunkering port of these vessels.

There are generally three main approaches for bunkering LNG to ships: ship to ship using barges, truck to ship, and finally through an LNG terminal and pipes directly to the ship. In the latter case, the LNG tanks could be also floating. Currently, LNG fuel bunkering is not possible in the port of Piraeus. There is one central LNG terminal on the small island of Revythousa in the gulf of Megara. There is only one importer, the Algerian company Sonatrach, which annually provides (and, based on the existing contract, until 2021), 0.68 billion m³ of LNG. The Revythousa island is situated in Attika, and its distance to the passenger port of Piraeus is 16.8 nautical miles. However, and keeping in mind the forthcoming emissions legislation and the fact that Piraeus is an important hub internationally and in the European Motorways of the Seas, it seems inevitable for the near future that LNG bunkering facilities will be realized.
THE NEXT EMISSION LEVEL, IMO Tier III, will be valid from 2016 onwards and is expected to demand an 80% reduction in NO_x levels compared to Tier I.

Passenger vessels are divided into two main categories—cruise and coastal shipping vessels—and are the main category of ships calling at the port of Piraeus. For 2012, the number of calls was estimated to be 5,000. Currently, all passenger vessels are powered by diesel engines, four-stroke for the smaller ones and the high speeds, and two-stroke for the larger ones and the cruise ships.

The methodology applied for an estimation of LNG demand for the port of Piraeus is based on two critical data: the number of bunkering processes that are taking place and the fuel quantities that are provided. For this purpose, and to accurately estimate LNG demand, a database was set up with all the ships that called at the port of Piraeus during 2012. The main characteristics of the ships used for their categorization were ship type; main dimensions; tonnage capacity; age; total installed power; service speed; and number of calls at the port. Apart from the ship type, the age and the tonnage of each vessel are essential inputs for the estimation of the projected number of bunkering processes with LNG in the coming years, because both inputs directly influence the decision of the ship owner to use an alternative fuel in a retrofit or newbuild ship in his fleet.

In addition, the assumption made for this estimation is that commercial ships up to an age of 10 years and passenger/cruise ships up to 15 years of age will show the tendency to switch to LNG use. Furthermore, it is assumed that the distance to the next bunkering station is 500 nautical miles, except for the coastal passenger vessels where of course their itinerary is known.

The results—relating only to passenger and cruise ships—are shown in Table 1.

However, besides the availability of bunkering infrastructures and the feasibility of an LNG terminal in the port of Piraeus (which are actually investments made by the port authority), the ship owner must thoroughly examine all possible alternatives for his ship. This is because the ship owner must, on the one side, comply with emissions legislation and energy efficiency standards; on the other side, he must run his business profitably with a focus on the environment. In the case of passenger and cruise ships, a company with a green profile is very advantageous and enables efficient marketing approaches.

The first (and most logical and easy to implement) solution, given that the Mediterranean sea is not an ECA, is to switch over from heavy fuel oil (HFO) or marine diesel oil (MDO) to marine gas oil (MGO) with low sulphur content. It is a straightforward solution with minimal intervention on the engine (fuel pumps and nozzles)—and then only in case of an engine burning HFO, because...
Table 1: Estimating Future LNG Demand at the Port of Piraeus

<table>
<thead>
<tr>
<th>SHIP TYPE</th>
<th>EXPECTED CALLS IN 2020</th>
<th>AVERAGE BUNKERING QUANTITY [m³]</th>
<th>SHIPS USING LNG [%]</th>
<th>SHIPS BUNKERING AT PIRAEUS [%]</th>
<th>ESTIMATED NO OF BUNKERING EVENTS</th>
<th>ANNUAL LNG DEMAND [m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small cruise</td>
<td>292</td>
<td>243.5</td>
<td>37%</td>
<td>60%</td>
<td>65</td>
<td>9,384.5</td>
</tr>
<tr>
<td>Large cruise</td>
<td>478</td>
<td>450.2</td>
<td>59%</td>
<td>60%</td>
<td>169</td>
<td>75,898.6</td>
</tr>
<tr>
<td>Small ferries (Crete)</td>
<td>1,332</td>
<td>89.6</td>
<td>0%</td>
<td>100%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Large ferries (Crete)</td>
<td>756</td>
<td>188.8</td>
<td>60%</td>
<td>100%</td>
<td>425</td>
<td>80,195.5</td>
</tr>
<tr>
<td>Small ferries (Cyclades)</td>
<td>664</td>
<td>43.8</td>
<td>44%</td>
<td>100%</td>
<td>502</td>
<td>21,978.0</td>
</tr>
<tr>
<td>Large ferries (Cyclades)</td>
<td>708</td>
<td>58.7</td>
<td>46%</td>
<td>100%</td>
<td>348</td>
<td>20,431.6</td>
</tr>
<tr>
<td>Small ferries (North Aegean)</td>
<td>116</td>
<td>85.4</td>
<td>0%</td>
<td>100%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Large RoPax (North Aegean)</td>
<td>408</td>
<td>132.5</td>
<td>44%</td>
<td>100%</td>
<td>180</td>
<td>23,849.8</td>
</tr>
<tr>
<td>Small RoPax (Dodecanese)</td>
<td>238</td>
<td>78.4</td>
<td>0%</td>
<td>100%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Large RoPax (Dodecanese)</td>
<td>274</td>
<td>261.7</td>
<td>60%</td>
<td>100%</td>
<td>164</td>
<td>39,742.5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1853</strong></td>
<td><strong>271,480.5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The cruise ferry Viking Grace is the first large-scale passenger ferry to be powered by LNG, with a length of 218 m and total passenger and crew capacity of 1,080.

Engines using MDO will not require any modification to burn MGO. The drawback to this solution is the higher operational cost due to the higher price of lighter low-sulphur fuels. In addition, and more importantly, in view of the forthcoming more stringent emissions legislation (for example, the Mediterranean being declared as an ECA), additional costly and partially unproven equipment should be installed on board. Such equipment could include scrubbers, selective catalytic reactors, exhaust gas recirculation devices and others that are continuously emerging in the market but which are still not in a mature phase to be installed onboard.

**The long-term outlook**

The use of LNG in existing ships will require major changes, as outlined earlier. LNG newbuildings are also more expensive...
compared to normal diesel-powered ships, due obviously to the higher cost of the engine, tanks, and control and safety equipment required. However, this higher capital cost is amortized by lower operating costs in the form of lower LNG prices, and by the fact that forthcoming and more stringent emissions and energy efficiency legislation will be met without having to additionally install new equipment or pay additional fees or penalties.

The investment cost consequently varies a great deal between the different abatement techniques that are applied on a ship. There also is a wide spread between different strategies in a fleet—for example, if a ship owner goes for newbuildings or retrofits or how much the green profile of a company should be strengthened. Table 2 shows average characteristic figures for retrofits and newbuildings comparing LNG options with diesel plus after-treatment options.

As outlined earlier, LNG prices vary heavily depending on the geographic area of bunkering. For example, in the United States, one could bunker LNG for $4 to $6 per MMBtu (one million British thermal units) from 2010 until July 2012, while for the same period the EU price was $7 to $11 per MMBtu; in Korea and Japan, the price increased to $10 to $18 per MMBtu. Fuel prices and their prediction for the years to come are an essential part of every strategic/financial decision in a shipping company, as they account for 50% to 70% of the operating costs of a vessel.

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Table 2: Average Cost Figures for LNG and Diesel Options

<table>
<thead>
<tr>
<th>COMPLIANCE STRATEGY</th>
<th>RETROFIT</th>
<th>NEWBUILDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGO—engine conversion, SCR and EGR</td>
<td>$180,000 + $75/kW</td>
<td>$140,000 + $63/kW</td>
</tr>
<tr>
<td>HFO and scrubber—scrubber and SCR</td>
<td>$600/kW</td>
<td>$2,200/kW *</td>
</tr>
<tr>
<td>LNG four-stroke dual fuel with tanks and equipment</td>
<td>$800/kW</td>
<td>$1,600/kW *</td>
</tr>
<tr>
<td>LNG two-stroke high-pressure dual fuel with tanks and equipment</td>
<td>$700/kW</td>
<td>$1,500/kW *</td>
</tr>
<tr>
<td>LNG four-stroke spark ignition with tanks and equipment</td>
<td>$800/kW</td>
<td>$1,600/kW</td>
</tr>
</tbody>
</table>

* including engine generators and so forth

We must bear in mind that passenger vessel operation in the Mediterranean certainly presents other critical challenges that have to be taken into account and possibly projected into the future when deciding whether to opt for LNG. But as things stand today, and given continuously rising diesel oil prices, the use of LNG fuel offers a very promising option for vessel owners and operators. MT

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