

# **THE NEXT GENERATION OF LARGE LNG CARRIERS FOR LONG DISTANCE AND HARSH ENVIRONMENTS**

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## **ABSTRACT**

Growth in the production and ocean trade of Liquefied Natural Gas (LNG) has averaged about 6.5% a year over time but has accelerated to about 9% in recent years. Driven by this commercial imperative, technology is being developed to allow new classes of LNG ships to be designed and built. These designs are pushing technological constraints and fueling innovation. The largest commercial impact on design is the jump in size from conventional LNG carriers of around 145,000 m<sup>3</sup> to large LNG carriers up to 265,000 m<sup>3</sup> capacity. The larger, size of these next generation carriers is causing the industry to research and develop many design optimizations including, the effects on membrane tank sloshing loads, larger block coefficients, and alternative tank technologies and propulsion options.

The paper will also look at even large LNG carriers and will discuss the economies of scale of very large ships while at the same time recognizing the challenges of interfacing such large vessels on either end of the supply chain. Further thoughts will be given on the use of large LNG carriers in high latitudes trades such as from Canadian Arctic Islands or from Russian Arctic.

## INTRODUCTION

The use of natural gas as a fuel is increasing steadily in many parts of the world. Because all imported LNG is transported by sea, the volume of ocean trade is the same as the volume of production. Growth in the production and ocean trade of LNG has averaged about 6.5% a year over time but has accelerated to about 9% in recent years. Unfortunately, (or perhaps fortunately for naval architects and shipbuilders) the producers and consumers of natural gas are often separated by considerable distances, e.g. Alaska to Japan, Qatar to the UK and the US, etc.

Driven by this commercial imperative, technology is being developed to allow a new class of LNG ships to be designed and built. These designs are pushing technological constraints and fueling innovation. The largest commercial impact on design is the jump in size from conventional LNG carriers of around 145,000 cbm to the larger carriers of 210,000 - 265,000 cbm. The larger, unprecedented size of these next generation carriers is causing the industry to research the effects of cargo sloshing loads on membrane tanks, larger block coefficients, and alternative tank containment technologies.

In addition to increases in capacity, there has been considerable development work carried out on alternative propulsion systems. Traditionally, LNG ships have used steam turbine propulsion because it provides a relatively simple approach to handling cargo boil-off gas (BOG) by using it to fuel the boilers. The increasing size of LNG ships, increasing gas prices and the ever-present need for increased power and efficiency of the propulsion plant, has led to investigations of a number of alternative options.

Many new land based LNG liquefaction plants are planned and under construction worldwide. This will result in shipyards being required to increase their capabilities to deliver multiple ships in a very short time-frame.

This paper will look into the future based on these developments and other developments and attempt to map out in which direction the next generation of LNG marine transport may develop.

## FUTURE OF LNG

The concept of liquefying natural gas was developed because it made gas simple to transport by sea. As a result, ocean trade in LNG and the demand for LNG carriers both became directly driven by the production of LNG. Because all imported LNG is transported by sea, the volume of ocean trade is the same as the volume of production.

Growth in the production and ocean trade of LNG has averaged about 6.5% a year over time but has accelerated to about 9% in recent years. Figure 1 illustrates that the total production and trade are expected to increase from about 300 million cubic meters in 2004 to about 550 million cubic meters in 2015. Table 1 summarizes the current world fleet capacity, as well as illustrating that the average ship size in the fleet continues to increase

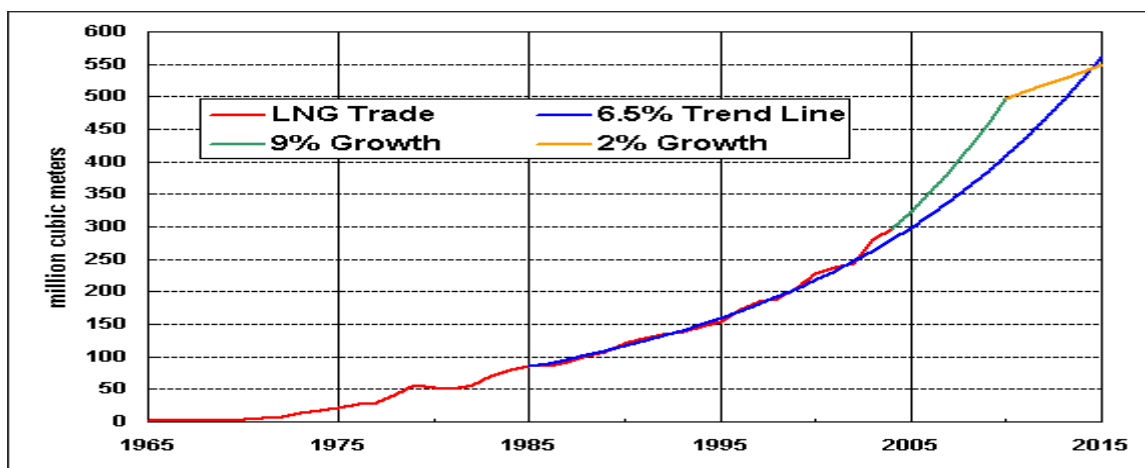
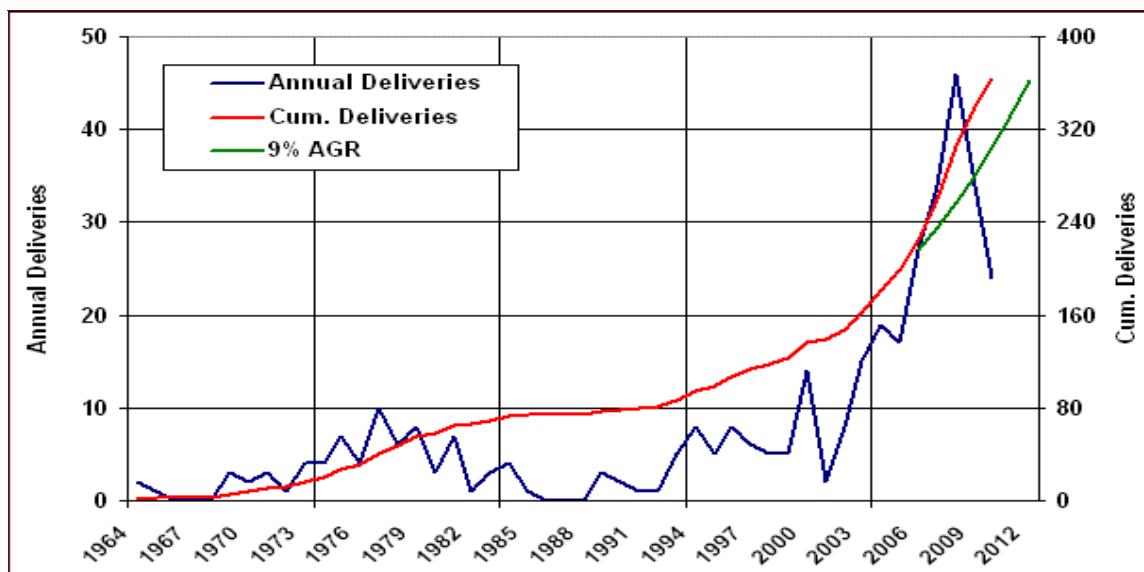


Figure 1 Growth in World Wide Production and Ocean Trade in LNG

Table 1 Current LNG Fleet Size as of December 2006

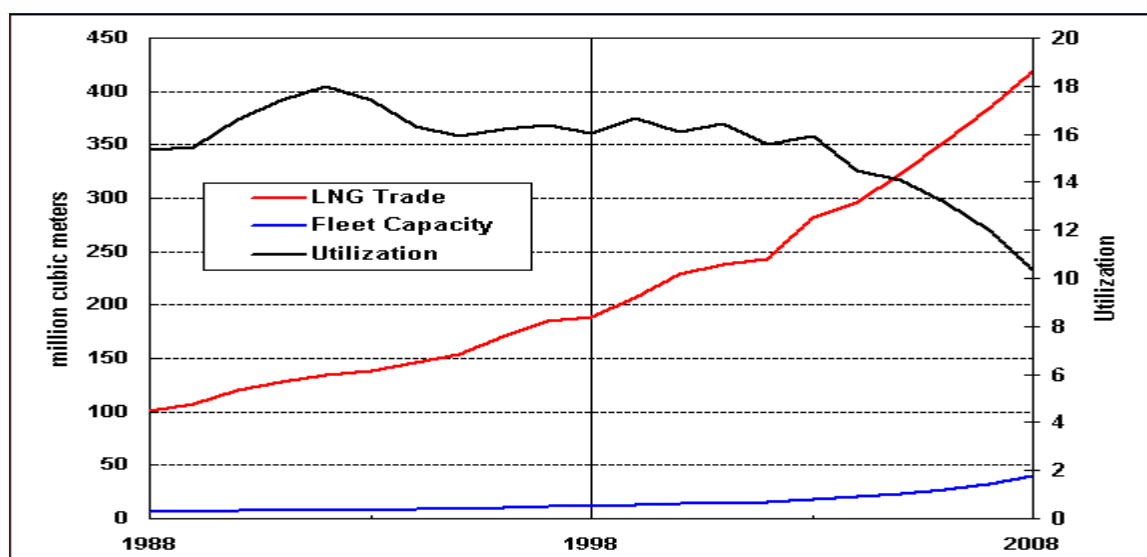
ACTIVE LNGC FLEET			
	# of Ships	Cubic Meters	Capacity/Ship
Active Fleet on 1/1/06	194	23,001,978	118,567
Additions	28	3,976,200	142,007
Deletions	0	0	
Active Fleet on 12/31/06	222	26,978,178	121,523
LNGC ORDERBOOK			
	# of Ships	Cubic Meters	Capacity/Ship
Ships on Order on 1/1/06	134	20,822,400	155,391
New Orders	28	5,762,500	205,804
Deliveries	28	3,976,200	142,007
Ships on Order on 12/31/06	134	22,608,700	168,722

Despite the relatively smooth growth in LNG trade shown on Figure 1, the construction of LNG carriers has been quite erratic, as shown in Figure 2. In particular, the current surge in the construction of LNG carriers started in 2000, but is now running well ahead of the projected growth rate.



**Figure 2 Delivery of New LNG Carriers and Growth in the Fleet**

If the volume of trade in LNG is compared to fleet capacity, as shown in Figure 3, it can be seen that the ratio of trade to capacity was reasonably steady at about 16, i.e., each ship made, on average, 16 trips a year. This ratio reflects the dominance of relatively short-haul trades, particularly from Southeast Asia to Japan and from North Africa to Western Europe. This measure of utilization is now decreasing as more LNG originates from Australia, the Middle East and West Africa, and as more of it is imported in to the U.S.



**Figure 3 Utilization of the LNG Carrier Fleet**

Keeping track of all the LNG projects that are in various stages of development is not simple, but currently there are approximately 35 - 40 projects scheduled to come on line over the next five years –four (4) in 2007, eleven (11) in 2008, fourteen (14) in 2009 and eight (8) in 2010. Each project may require 6 - 12 ships.

## COMMERCIAL DRIVERS FOR LARGER CAPACITY TANKERS

The reduction of productivity per ship that is caused by increased distance will be offset by the use of larger ships. The standard LNG carrier looks much the same as it did 30 years ago, but it has grown from 120,000 cbm to over 155,000 cbm (an increase of about 30%) as shown in Figure 4. The current next generation LNG carrier boom has broken this mold.

The first of these large, next generation LNG carriers of about 210,000 – 215,000 cbm capacity were ordered in late 2004, for delivery in late 2007, and the first ships of 265,000+ cbm were ordered in early 2006, for delivery in late 2008. From now on it is anticipated that most new long-haul trades will use large ships while shorter trades will continue to use conventional sized ships, which may continue their evolutionary increase in size as terminals and waterways expand. In addition, there are still a few short-haul trades that will continue to utilize a small number of 25,000 to 75,000 cbm LNG carriers.

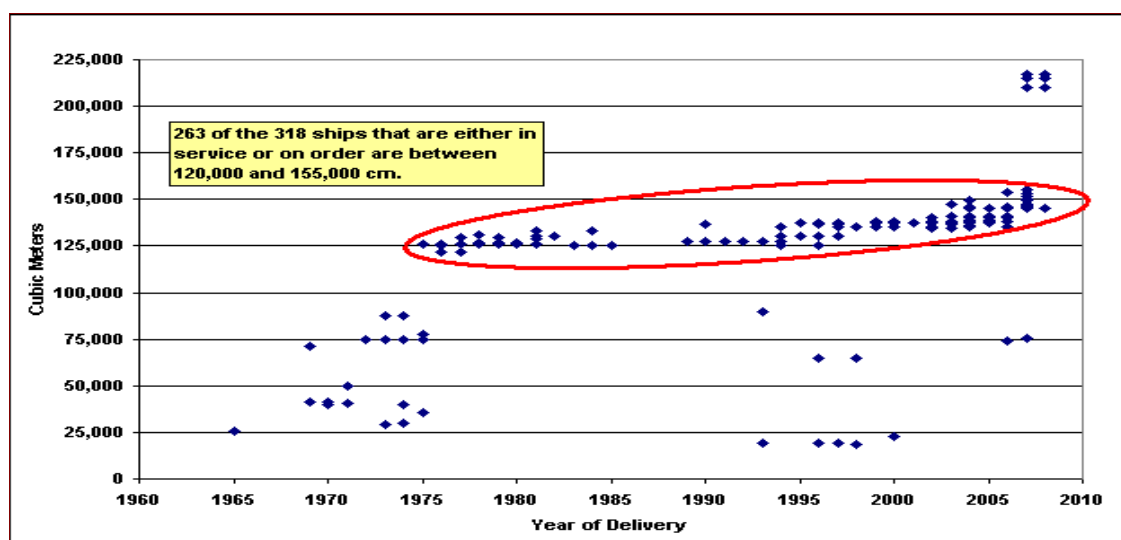


Figure 4 Growth in the Average Capacity of an LNG Carrier

## SHIP DESIGN DEVELOPMENT

### Increasing LNG Ship Size

As discussed above, over the past 40 years there have been a series of “growth spurts” in LNG ship size. The industry is starting to see another jump from conventional sized carriers to the next generation of large LNG carriers of 200,000 to 267,000 cbm capacity. This large jump in size is driven by project economics and enabled by technology improvements. This section introduces these improvements in technology and the considerations used in design of the next generation LNG carrier.

### Large LNG Design

Particulars for the next generation of large LNG carriers that have been developed are shown in TABLE 2. Depending on which yard is designing the vessel, dimensions and

capacities may vary due to the differences in containment system designs, propulsion choice, and shipyard constraints.

**Table 2 LNG Carrier Particulars**

Capacity (cbm)	210,000	217,000	243,000	267,000
Length (m)	315.0	315.0	335.0	345.0
Beam (m)	50.0	50.0	51.0	55.0
Draft (m)	12.0	12.0	12.0	12.2
Depth (m)	27.0	27.0	27.0	28.0
Number of Tanks	4	4	5	5

General arrangements of the different sized vessels are very similar. Containment system and propulsion choices results in some of the major differences in designs. For example, a gas turbine ship requires less engine room space so that the engine room bulkhead can be moved aft to allow more volume for cargo. As a result, in the 243,000 cbm Gas Turbine electric propulsion (GT) LNG carrier design each tank is about 1.5 m longer. This shift in cargo center of gravity prompted designers to explore the possibility of locating the house forward to offset the shift in weight. Further arrangement flexibilities are possible since with electrical propulsion systems, gas turbine generators and high pressure gas can be located above the engine room.

LNG carriers larger than 200,000 cbm generally have 5 cargo tanks instead of 4. A four tank design in the longer ships, results in longer individual tanks. This creates issues with sloshing in the membrane tanks. In the Moss spherical tank design, 4 large tanks results in too wide a beam for shipyard capability and for tank strength requirements. Large LNG ships with SPB tanks fitted with swash bulkheads, both longitudinally and transversely may be an acceptable solution.

Some work has been done on even larger LNG tankers, up to 400,000 cbm capacity, but at this time these do not appear to fit the evolving trades for a number of reasons. These ships will either have a very “distorted” hull form, very high beam/draft ratio, which will lead to propulsion inefficiencies, if the draft is kept low; or will have very restricted trading opportunities if given a more normal draft for ships of this size. This work is still ongoing, but based on a high level review of all factors involved, ship size, terminal requirements, shipbuilding restrictions, market flexibility etc it seems that the next generation of LNG ships may settle down in the 225,000 cbm range

### **Single vs. Twin Screw**

For the next generation of large LNG carriers (greater than 210,000 cbm), twin screw designs are preferred, in contrast with other large ships, such as container ships and large tankers which are single screw. Shallow draft restrictions of around 12.0 m, imposed by many LNG loading and regassification terminals limit the size of the propeller, and therefore, limit the propulsion efficiency that can be gained from a single screw hull form.

High beamed, shallow draft ships can benefit significantly in propulsive efficiency by using twin screw arrangements. Model testing and CFD analysis have shown that ships with a wide beam and shallow draft, relative to their beam, will benefit from a twin screw, twin skeg configuration. More uniform wake fields are generated by the twin skegs creating greater propulsive efficiency. There can be a cost penalty in constructing twin screw ships, but it is outweighed by the gain in efficiency and reduction in fuel costs or operational costs over the life of the ship. Further the twin screw arrangement enhances maneuverability and gives a degree of redundancy in the propulsion which can reduce risk and improve safety.

### **High Block Coefficient**

Generally, conventional single screw LNG carriers and large single screw containerships have a block coefficient in the range of 0.72 - 0.75. Recent work done in support of the larger next generation LNG carriers shows the benefit in increased hull efficiency and increased cargo volume by increasing block coefficients to approximately 0.80 and concurrently moving the LCB forward.

Although care must be taken in applying this approach, it has benefits in maximizing cargo capacity, without increasing the ship's beam. In general, the speed loss in rough water is more a function of beam, than of block coefficient. This development suggests that larger capacity LNG ships can be built without major changes in dimensions, particularly without increasing draft significantly.

### **Cargo Containment**

Today, there are four available approved LNG containment systems for application on large ships. These are the Moss IMO type-B Spherical tank system; the Self-supporting, prismatic shape, IMO type-B tanks or SPB system, and the two membrane systems, the GTT Mark III and NO 96 systems.

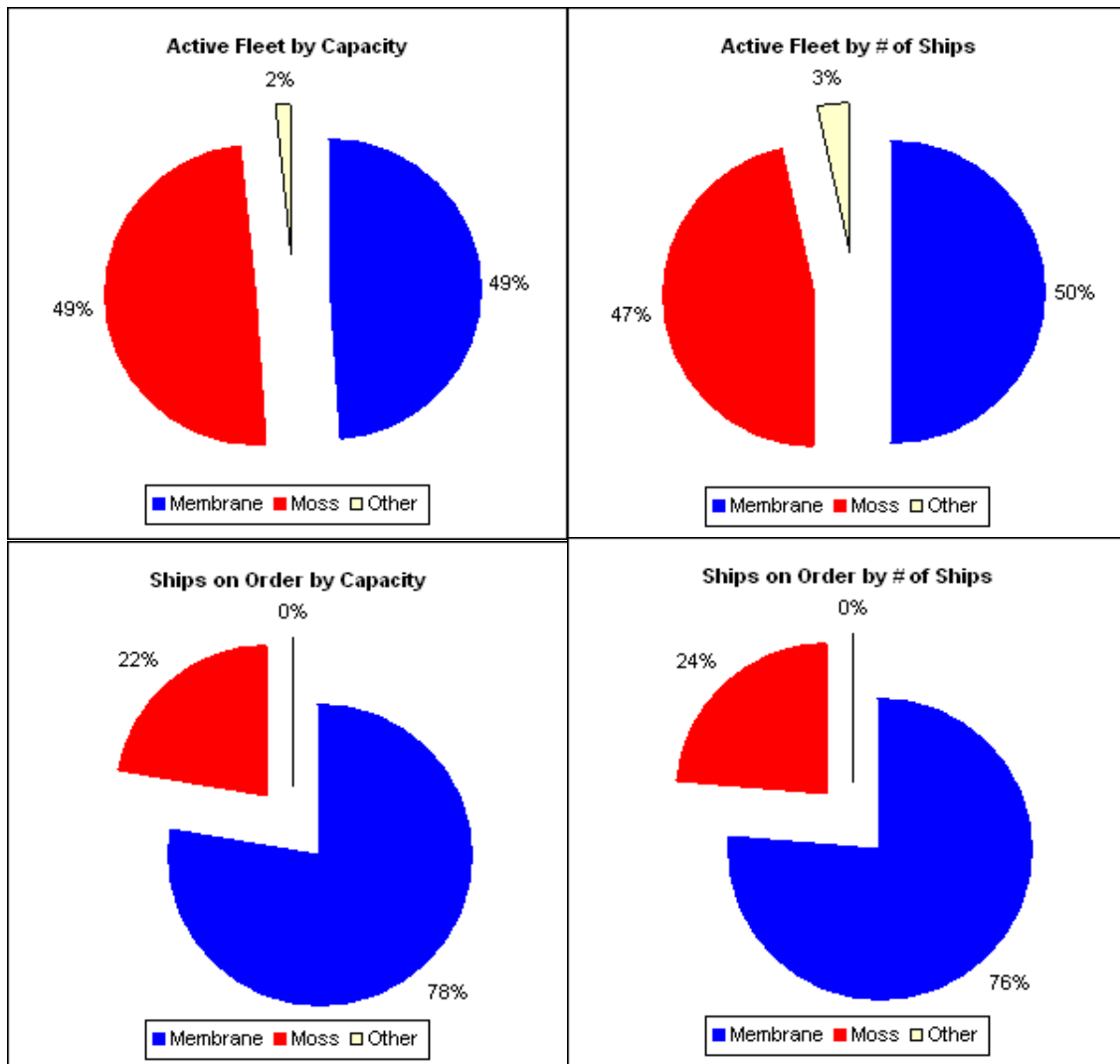
In current order books, see Figure 5, the membrane system has become increasingly more popular. Part of this increase in the use of membrane tanks is due to the higher cost of bringing Moss ships through the Suez Canal and part is due to the fact that the three largest Korean shipyards have adopted membrane systems as their primary solution for LNG ships.

There have been concerns over the robustness of membrane tanks to sustain sloshing loads and recently there have been further concern over the GTT MarkIII membrane system integrity with "gluing" problems at yards in Europe and Korea.

The SPB tanks have been used on only 2 ships so far, the Kenai LNG ships built in Japan, but there have been some recent orders for such ships from Korea and ongoing design development seems promising. The newest designs of SPB tanks will move from the use of aluminum to stainless steel for the tank structure.

## Cargo Tank Sloshing

The effect of tank sloshing on containment systems is a challenging issue in designing large LNG vessels because numerical and experimental testing has only been verified on conventional sized vessels. Existing methods use a comparative analysis by testing new designs and comparing them to test data and performance data collected during operations. If sloshing pressures are below results collected from vessels in service, they are deemed acceptable. Since there are no LNG carriers greater than 166,000 cbm in service, the applicability of these test methods is under discussion.



**Figure 5 Containment System Type as Percentage of LNG Carrier Fleet as of December 2005**

In addition to model testing, full scale testing has been proposed by applying strain gauges to the inner hull to measure stress levels in membrane tanks. North Atlantic conditions are severe and testing has shown that conventional size membrane containment systems must be restricted to a loading level of less than 10% or more than 85% to limit sloshing loads within acceptable levels. Moss type and SPB tanks are not



prone to excessive sloshing due to their shape and construction method and, therefore, no loading restrictions apply to these types of tanks.

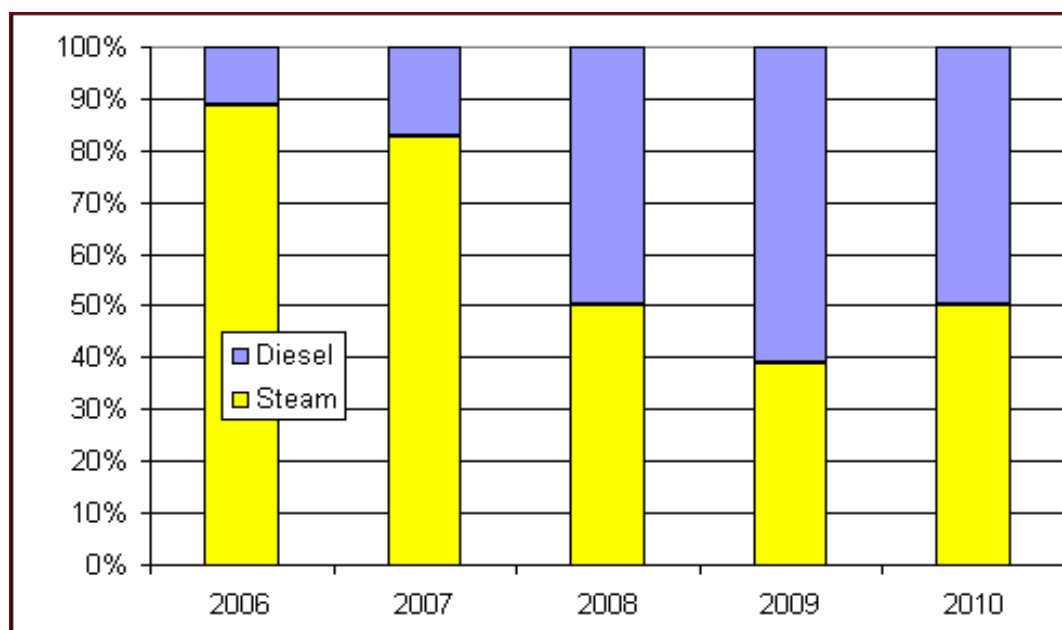
### Boil-Off Gas and Reliquefaction

The challenge that is prevalent with all tank designs is how to deal with the natural boil off gas (BOG) from the tanks, since in all systems the LNG is carried at ambient pressure and at its boiling point of around -163 degrees Celsius. In conventional steam ships that were built when gas prices were low, the BOG is burned as fuel in boilers to create steam that supplies the main propulsion. At the time the ships were built, this was the lowest cost, simplest option. Now, as gas prices keep rising, the projected price of gas as the ship's fuel has a large impact in the design of LNG carriers. This has caused the industry to seek alternative propulsion systems, such as directly connected slow speed diesels with reliquefaction (DRL), gas turbine electric propulsion and medium speed dual fuel diesel engines with electric propulsion.

If the market price of gas significantly exceeds that of heavy fuel oil, it is likely that reliquefaction on board the vessel will be cost effective. Capital costs of this system are high, but burning HFO in a slow speed diesel is currently the most efficient means of marine propulsion, as exhibited by the world fleet of commercial ships where it is used almost exclusively.

### Propulsion Alternatives

At present, the majority of LNG carriers are steam-powered, using BOG for part of their fuel requirements. The first diesel-powered LNG carriers are now in service, and Figure 6 shows the ratio of steam to diesel powered ships in the order book. About half the diesel-powered LNG carriers on order will have dual-fuel medium-speed diesel-electric (DFDE) plants and half will have direct-drive slow-speed diesel plants with BOG reliquefaction.



**Figure 6 LNG Carrier Propulsion Systems**

Owners are weighing decisions on shipyard scheduling, efficiency, emissions regulations outlook, fuel savings, capital costs, simplicity of design, crewing, and projected gas and HFO prices. Because emissions are such a popular political issue at present, serious consideration is being given to the use of gas-turbine propulsion as an alternative. As a result, there is now considerable uncertainty as to the optimum system, with more work required.

## **EMISSIONS**

### **Overview**

Legislation and regulation pertaining to marine emissions is quickly evolving both regionally and globally. To remain competitive, the need for designing and implementing affordable solutions to reducing emissions is inevitable.

This section addresses current events and issues surrounding NO<sub>x</sub> and SO<sub>x</sub> emissions, greenhouse gas (GHG) emissions, emissions trading, and other related topics drive that ship design. This section concentrates more on the DRL and CoGES propulsion alternatives, since they are likely to be in direct competition as candidates for the next generation of large LNG carriers.

### **Current Legislation and Requirements**

International regulations for air quality produced by ships are mandated by the International Maritime Organization (IMO) and the U.S. specifically is mandated by the U.S. Environmental Protection Agency (EPA) and several other regional and state agencies.

In May 2005, an amendment to IMO MARPOL Annex VI came into effect regulating Sulfur content in fuels and levels of NO<sub>x</sub> emissions. Marine heavy fuels are required to have no more than 4.5% Sulfur and in SO<sub>x</sub> Control Areas (SECAs), 1.5% Sulfur. NO<sub>x</sub> emissions are regulated to 17 g of NO<sub>x</sub>/kW-hr, which is the same as required by EPA for tier 1 diesel engines.

In the European Union, all passenger vessels on regular service from any port in the EU must comply with a 1.5% Sulfur in fuel limit. Additionally, any ship berthed in an EU port must comply with the new 0.2% Sulfur in fuel limit for any fuel burned while docked. The EU has recently begun an Emissions Trading Program as a result of the Kyoto Protocol.

### **Exhaust Gas Emissions from Large LNG Carriers**

Emissions have been calculated for equivalent Gas Turbine and DRL ships for each segment of a hypothetical long haul LNG trade. The results are provided in Table 3 and TABLE 4. It is assumed that the GT ship will run on B.O gas at all times. It should be noted that the gas turbine emissions are dependent on the engine load, and that this has been accounted for in the schedule. If there is no gas available during unloading and loading due to terminal regulations, the emissions are equal to those provided for the DRL, where the electrical load is produced by the diesel generators running on MGO. There is no anticipated need to run the gas turbine on MGO except for in emergencies.

**Table 3 Exhaust Emission Rates for the CoGES Lm6000 Plant**

<b>Part load GT%</b>	<b>100</b>	<b>80</b>	<b>60</b>	<b>40</b>	<b>20</b>
<b>Total GT Electrical kW</b>	<b>41,162</b>	<b>32,950</b>	<b>24,724</b>	<b>16,502</b>	<b>8,308</b>
NO <sub>x</sub> as NO <sub>2</sub> , g/kW-hr	1.95	1.69	1.49	1.33	1.34
CO g/kW hour	0.06	0.12	0.26	0.66	2.27
CO <sub>2</sub> g/kW hour	414	432	461	517	706
HC g/kW hour	0.005	0.007	0.017	0.070	0.430
Particulates	0.010	0.010	0.010	0.010	0.010
SO <sub>x</sub> as SO <sub>2</sub> g/kW-hr	0	0	0	0	0

**Table 4 Exhaust Emission Rates for the Diesel Engine Propulsion System**

<b>Diesel Engine Exhaust Emission Rates [g/kWh]</b>	<b>NO<sub>x</sub></b>	<b>SO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>Particulates</b>
2 Stroke Diesel HFO (2.5% Sulfur)	17.00	12.90	580.00	0.50
4 Stroke Diesel HFO (3.5% Sulfur)	12.50	13.60	620.00	0.40
4 Stroke Diesel MGO/DMA ( 0.2% Sulfur)	12.50	1.30	620.00	0.03

### **Emissions Requirements of the Future**

Controversy for shipping in the future surrounds the topics of how low Sulfur levels in fuels will need to be and whether or not ships will count toward sources of emissions toward future cap and trade emissions markets, especially for CO<sub>2</sub> in the US. It is obvious that requirements will continue to tighten on a global scale, but it is unclear by how much and when. Currently, only voluntary emissions trading is done in the US.

### **HARSH ENVIRONMENT LNG SHIPPING**

The LNG trade is growing world wide, and the traditional trade routes are also expanding beyond the traditional warm water environments that have been enjoyed for many years.

One of the few “harsh environment” LNG trades has been that from Alaska to Japan, which has been successfully carried on since 1969. The trade is currently carried on using two 89,000 cbm LNG ships built in Japan using the SPB containment system, Figure 7. These ships have been very successful in service and serve as a good analog for other harsh environment trades.



**Figure 7 – Polar Eagle LNG ship – Kenai, Alaska**

In the late 70s, early 80s there was a considerable effort devoted to developing LNG ships capable of delivering LNG from the Canadian Arctic to the East Coast of North America, but falling energy prices of the mid 80s put that project on the shelf.

More recently the Sakhalin LNG project has been the first to require that LNG carriers be built to ice classification, and for the past few years work on high latitude–harsh environment LNG ships capable of servicing terminals in the Baltic, Arctic Russia, the Canadian Arctic Islands and even northern Alaska has been ongoing. Development a 220,000 cbm LNG ships designed for such trade using a 4 tank SPB containment system is underway.

Oil tankers for such trades are already being built. Figures 8 shows such a design 3 of which are being built in Korea, with the first due for delivery in Dec 2007. Such ships will give much needed information on high latitude operations which will allow high ice class LNG ships to be successfully developed which will maintain the excellent safety record of this sector of the energy shipping business.



**Figure 8 – 70,000 dwt Tanker for Russian Arctic – Twin Azipod Propulsion**

## **CONCLUSIONS**

Natural gas is the fuel of choice for many applications and its increasing popularity will keep the demand for efficient shipping high.

Large LNG ships are here to stay, although the increasing size of LNG ships may have already reached a natural limit, at least for the time being based on current infrastructure and markets.

We will continue to see developments in improved LNG containment systems, and propulsion systems.

New projects with particularly challenging conditions such as shipping LNG from the Russian and Canadian Arctic will provide exciting challenges for naval architects, marine engineers and shipbuilders in the years ahead.