Modern LNG Carrier Technology

Finding the right balance

Photo courtesy © DSME

March 2019: Four Yamal Arc 7 LNG carriers at Daewoo Shipuilding & Engineering (DSME)

Technology Report#05 - Autumn 2019

BUREAU VERITAS

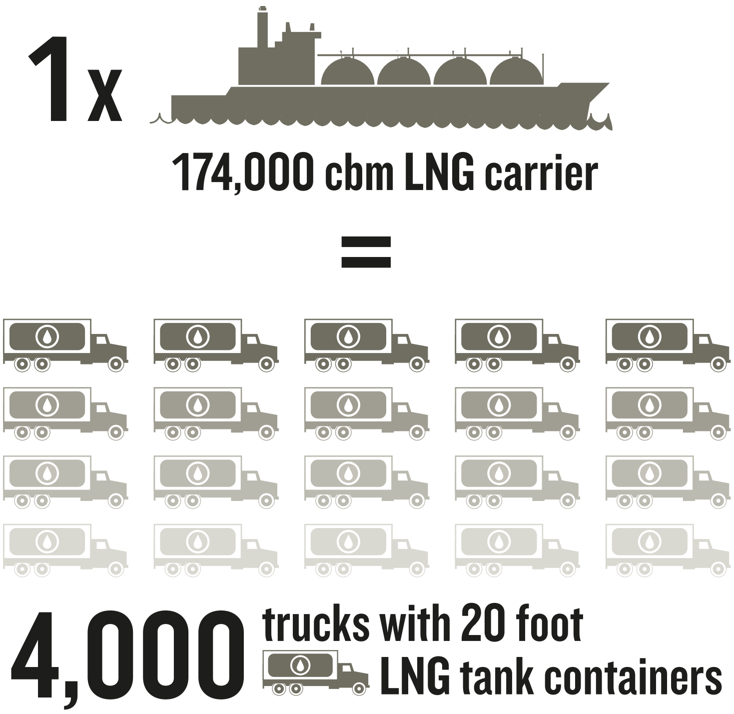
SEABORNE LNG

AN EXCITING AND EVER-EVOLVING MARKET

The seaborne carriage of LNG has only been made possible, and been enabled by, significant levels of creativity. We have gone from prototype LNG carriers, which originally resembled the general cargo ships of the day (like the Beauvais), to the modern icebreaking LNG carriers that we see in operation today, with the latest membrane containment and podded propulsion systems installed on board.

To take natural gas, reduce its volume 600 times by cooling it, and ship it across the oceans at a cryogenic temperature, was a pretty big idea – an idea that required an equally big leap in development, when the first experimental ships took to the seas in the late 1950s, and that has seen further significant leaps over the last 60 years. Bureau Veritas (BV) has been there all the way, addressing safety and risk while supporting and helping foster innovation.

Cooling natural gas to minus 163 degrees Celcius reduces its volume 600 times



© Noun project/Patrick Trouvé, DR

The Beauvais.

Yamal LNGC.

FINDING THE RIGHT BALANCE

THE GLOBAL ARCHITECTURE OF LNG CARRIERS

580 LNG carriers afloat today

The LNG carrier fleet has grown significantly – especially in the last few years. Today, the fleet comprises just over 580 ships, including small-scale FSRU units classed as ships and about 20 laid-up older ships, some of them currently being converted into FLNG, FSRU or FSU units. In the early 2000s, the fleet of ships was only around 120 units, including small-scale LNG carriers.

The evolution of marine LNG has been defined by creativity, particularly when it comes to containment and propulsion. The relationship between the two is significant. How do you find the right balance between retaining cargo and consuming boil-off? How do you most efficiently allow for flexibility in charter markets so that, for example, a ship can change routes and terminals to adapt to a new operating pattern?

In the early days, when ships were contracted for long periods (typically 20-25 years), they were tailor-made for specific routes: ship speed, voyage duration and quantity of landed cargo were pre-determined. But today, more speculative orders covered by relatively short-term charter contracts are seeing a demand for greater built-in flexibility related to size, propulsion systems and cargo management.

At Bureau Veritas, this demand for flexibility is where our experts focus a lot of their time, helping clients find the right solutions and addressing the related safety, regulatory and risk aspects.

The emergence of membrane systems as the dominant technology

After the early prototype containment technologies, two dominant families rapidly emerged – the French membrane-type containment systems developed by Gaz Transport and by Technigaz, and the self-supporting type ‘B’ containment systems developed by the Norwegian company Moss Maritime and the Japanese IHI Group. Today, the merger of the two French companies – GTT – dominates LNG containment, with variants of the NO96 and Mark III membrane systems installed in most ships being built and entering operation.

Evolution to 2-stroke slow speed propulsion

The evolution from steam turbine ships, to dual fuel diesel electric (DFDE) ships and, now, 2-stroke dual fuel powered ships has been relatively quick and has delivered significant advances in efficiency. But the search for optimal systems continues and the key issue remains the relationship between propulsion and containment. For example, do you need a re-liquefaction plant? Or can you manage without one? The market continues to expand and demand for cleaner fuels is increasing. There are some big orders for LNG carriers in prospect, and small-scale LNG is taking off. So, there are some big decisions to be made.

BV will always be there to help stakeholders make the best safety and commercial decisions based on the best technical insight, as the exciting LNG sector continues to evolve.

YAMAL LNG
A NEW TECHNOLOGICAL FRONTIER

It is hard to believe that the Yamal LNG carrier project for the first 15 icebreaking ARC 7 ships will soon be completed. The project embodies the creativity that has characterized the development of seaborne LNG.

By the autumn of 2019 the newbuilding phase will be completed on a project that many, perhaps, thought would not see the light of day.

These LNG carriers have brought with them significant firsts – notably their combination of icebreaking capability (stern-first in heavy ice), winterization and technologically advanced podded propulsion – all crucial elements for operating in some of the harshest conditions in the world. Their icebreaking ability and their size makes these dual class BV and Russian Maritime Register of Shipping (RS) carriers unique among Arctic vessels and, moreover, within the LNG carrier segment.

Bureau Veritas Senior Vice-President for North Asia, Claude Maillot and Korea Chief Executive for BV, Christophe Capitant are greeted by Lee Sung-Geun, CEO, Daewoo Shipbuilding & Marine Engineering (DSME) and Jung Dae-Seong, Executive Vice-President, DSME during the naming ceremony for the four Teekay managed Yamal LNGCs in April 2019.

THE IMPORTANCE OF LEADERSHIP AND TEAMWORK

The BV teams involved in the Yamal LNG project have dedicated their expertise to every stage – from the initial discussions, through plan approval and construction to, now, the ships' operational lives.

BV had been involved with a wide variety of Arctic projects for well over two decades, but this project presented the BV and RS teams with fresh challenges. Each ship was to be equipped with technologically advanced azipod propulsion (3 units of 15MW each), high winterization levels and a hull reinforced to Polar Class 3 level (equivalent to ARC7 of the Russian Maritime Register of Shipping, RS). The ships' size (at 299m in length and 50m beam) for a cubic cargo capacity of 172,000 cu. m required that they be fully autonomous in ice.

So, providing assurance that the project risks could be effectively addressed was vital. The podded propulsion, structure, containment, winterization aspects and issues related to vibration all had to be addressed, and their inter-dependencies had to be recognized and understood. BV had an excellent working relationship with the Russian Register, whose ice expertise, combined with BV's structures and gas leadership, were vital. Testing at Aker Arctic's ice towing tank was a key area of activity.

The project has been a massive undertaking, and there has been excellent feedback on the classification aspects from both the yard and the owners, and on the close and effective cooperation between RS and BV.

"During the course of the history making Yamal ARC7 LNGC project, there were tremendous challenges and obstacles when developing & building the World's 1st ARC7 LNG carrier. However, upon her completion she has successfully proven herself to be an outstanding shipping solution in the Arctic and Northern Sea Route all the year round.

Over a number of decades, BV has been one of DSME's most reliable and trustful partners and we could not imagine our great achievements on the Yamal LNGC project without BV's dedication and professional expertise.

We strongly believe that BV and DSME will build upon such fruitful collaboration on other valuable projects and deepen our win-win partnership for many years to come."

Dae Seong JUNG,
Executive Vice President,
Head of Production Business Unit,
DSME

DSME
DAEWOO SHIPBUILDING & MARINE ENGINEERING CO.,LTD.

Christophe Capitant, Bureau Veritas Marine & Offshore Chief Executive for Korea - seen here with DSME's Jung Dae-Seong in April comments: "We are so proud to be associated with this project and to have had the opportunity to work so closely with DSME who have again demonstrated the depth of their expertise and organization as a world-beating shipyard. We very much look forward to the opportunity to work on future projects."

BUREAU VERITAS ICE AND LNG EXPERTISE FOR THE FUTURE

A more recent star project in the world of LNG-fuelled ships is the Ponant icebreaker – the world's first LNG-powered, hybrid-electric passenger vessel to navigate through polar waters (see picture below). The ship's innovative design – Polar Class 2 – surpasses Polar Code regulations for environmental protection and provides unparalleled ice-breaking ability.

Projects like the Arctic LNG-2 will soon be sanctioned and will need additional LNG carrier capacity. BV is ready, and has the expertise, to support the project stakeholders to meet the safety and pollution prevention requirements.

BV LNG and ice class expertise combine again in the classification of Ponant's innovative icebreaking LNG-hybrid powered expedition cruise ship, Le Commandant Charcot, *due for delivery in 2021.*

A distinguished paint job: the LNG carrier Christophe de Margerie, *the first of the Yamal ARC 7 ships to be delivered, was named for the former CEO of TOTAL who was known for his big mustache.*

AN EFFECTIVE PARTNERSHIP: DUAL CLASSIFICATION PROVIDES A STRONG TEAM

BV works with RS to benefit Arctic LNG transportation

Classification societies BV and RS can look back on a long cooperation in the classification of the cutting edge Yamal gas carrier fleet. RS with its ice class expertise and hands-on experience in membrane LNG containment systems designed for ice-going ships and BV with the long experience in all types of containment systems and LNG carrier innovation have been closely in partnership for the Yamal LNG newbuilding program.

The series of 15 state-of-the-art Arc 7 Yamal LNG carriers, along with two Arc 7 condensate tankers, under construction at DSME has been a primary focus area for the joint efforts of BV and RS dual class.

A further joint project is an LNG bunker vessel under construction at Keppel Nantong shipyard. The BV-RS dual class arrangements feature a practical combination of strong expertise and specific knowledge to consolidate added value for high-technology projects for the benefit of all involved.

Sovcomflot: a shipowner's perspective on a good partnership

In 2017, Sovcomflot took delivery of Christophe de Margerie, the first icebreaking LNG carrier ever built. Working on this pioneering vessel proved to be an excellent example of cooperation set by Sovcomflot, the ship-owner, together with DSME, the shipyard, and the class societies BV and RS.

From the moment of her delivery two years ago to today, the vessel has performed exceptionally, even when operating in challenging ice conditions. In 2018, SCF placed orders for three conventional 170,000-cbm LNG carriers at DSME with BV as class. Officers working onboard Sovcomflot's LNG carriers undergo mandatory extensive in-house training at a corporate training centre in St. Petersburg. This centre is equipped with a state-of-the-art LNG operations simulator certified by BV.

© Sovcomflot

THE KEY CHALLENGE TODAY - LNG CARRIERS AS A GLOBAL SYSTEM

MATCHING CONTAINMENT AND PROPULSION WITH SUPPORTING EQUIPMENT

Technical developments have helped the LNG carrier industry to evolve very rapidly in recent years. Cryogenic cargo containment system evolution, new engines and re-liquefaction systems have been at the core of recent developments to respond to charterers' and shipowners' needs.

The main operational challenge is the right combination of these systems on board. The operating profile of the modern LNG carrier has changed – flexibility is now key, with ships calling at different loading and offloading terminals and requiring high fuel and energy efficiency. Having the right equipment on board is vital for all stakeholders.

Containment systems

Containment systems commonly used for large LNG carriers, such as GTT Membrane and Moss type B systems, have evolved significantly. The, boil-off rate guaranteed by the developers of the systems has been reduced by half, from values typically in the range of 0.15% of the tank volume per day in laden condition, to values as low as 0.07%. GTT have also adapted their membrane technologies for applications such as FSRUs, which have specific needs in term of sloshing reinforcement.

Engines

New technologies able to use boil-off gas as fuel, such as dual fuel and gas-only engines, were developed in the early 2000s and implemented for the first time in LNG carriers when the first ship with dual fuel diesel electric propulsion, *GDF Suez Global Energy*, was delivered by Chantiers de l'Atlantique yard in 2006.

More recently, 2-stroke engines, both high and low pressure gas injection, have become the preferred option, with installation of the first MAN B&W ME-GI engines on the *Creole Spirit*, delivered early in 2016, and the first Winterthur Gas & Diesel X-DF engines on the SK AUDACE eighteen months later. These new dual fuel engines also allow different fuels to be used, offering additional flexibility in terms of fuel cost optimization.

Re-liquefaction technology

Re-liquefaction equipment has been widely used in LPG and LEG carriers, but the technology is more complex when charters and owners want to be able to re-liquefy LNG boil-off gas. This demand for fuel flexibility has driven leading companies such as Wartsila, Cryostar, Air Liquide and Babcock to develop a second wave of re-liquefaction systems, which are being installed in most of the new LNG carrier projects today.

The question of boil-off

The ideal LNG carrier is designed not to waste gas – this means the total system is designed to avoid producing either too much boil-off or too little.

If the boil-off rate is higher than required by the ship then there are two options: either re-liquefy with a

Boil-off rate explained

Nearly all LNG carriers are designed to burn their own cargo to power their engines and meet auxiliary power requirements. This fuel is the 'boil-off' gas from the cargo containment systems. The gas, liquefied by cooling to –163 degrees C, is constantly trying to re-gasify. The rate at which it does so is known as the boil-off rate (BOR). Cargo containment systems, predominantly efficient membrane systems these days, are designed to minimize the BOR to maximize the cargo that can be delivered. But as some boil-off is needed for propulsion, finding the right balance between fuel consumption and production of boil-off for fuel is vital.

re-liquefaction plant or burn the excess in a gas combustion unit (GCU).

If the boil-off rate is too low then either boil-off must be forced to produce fuel for the ship or fuel oil must be used as an alternative.

Traditionally this balance relies on a known speed and distance for the laden leg. Today, with shorter charters becoming the norm – or even spot trading a factor – there is demand for ships that can operate efficiently with different operating criteria.

The table 1 compares the boil-off rates and fuel consumption of the three main ship architectures in use today. The 2-stroke, low consumption and low BOR ships being delivered today are significantly more competitive than previous generation LNG carrier tonnage.

Table 1 – The three main ship architectures trading today, clearly demonstrating the evolution of ship design and the demands of the market

Propulsion	Typical size '000K	Cargo Containment System (CCS) Boil-off rate (BOR) - daily	Approximate daily fuel consumption (tons) at a design speed of 19.5 knots
Steam*	130-140	0.15%	150-180
DFDE	155-175	0.1%-0.125%	120-130
DF 2-stroke**	170-180	0.07% – 0.085%	90-100

* Modern steam turbine LNG carriers are larger (170-180k) and have a reduced BOR (0.1%) with DFDE propulsion systems. Their fuel consumption is in the range of 120 tons/day.
** The notable exceptions are the fuel oil powered Q-Flex and Q-Max ships developed for Qatar Gas.

Cargo Containment focus – GTT systems: constant development

BV is closely involved with containment system developers, assessing their different designs. Assessment is based on the IMO IGC Code and class regulations, which cover the safety aspects to be considered for approval of the technologies.

Today, the clear preference of most owners ordering new LNG carriers is for Gaz Transport and Technigaz (GTT) systems (see Table 2). GTT has been developing improved systems to align with the market demands for improved insulation and improved resistance to sloshing pressure.

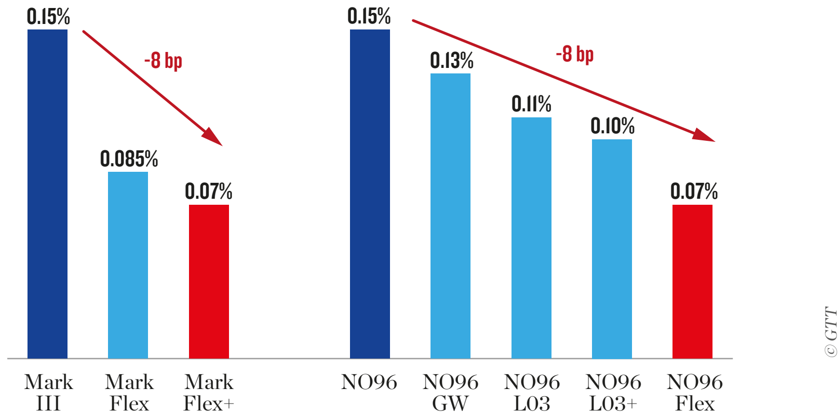
Table 2 – All the modern GTT containment systems approved by Bureau Veritas since 1995

Propulsion	Typical size '000K
NO96 / NO96GW	(FA) BV Class Ships / 1995
Mark III	(FA) BV Class Ships / 2005
CS1	(FA) BV Class Ships / DA in Nov. 2004
NO96 L03	(FA) BV Class Ships / DA in Aug. 2013
Mark III Flex	(FA) BV Class Ships / DA in Dec. 2014
NO96 L03+	DA Feb 2015
MARK III Flex HD	DA May 2015
Mark V	DA Oct 2015
MARK III Flex +	**DA Dec 2017**
NO96 Max	AiP
MARS (LPG)	AiP September 2017
NO96 Vacuum	AiP
Mark III and NO96 series (LPG/LEG/LNG)	AiP
MARK III (ARCTIC)	AiP
NO xx	AiP
NO 96 Flex	**AiP September 2018**
Mark Fit and Brick	AiP ongoing
Mark III Flex for Arctic Operations	AiP August 2019
NO96 LO3+ for Arctic Operations	AiP August 2019

The most boil-off performant systems are shown in bold.
FA = Final assessment. A ship is classified and the system installed on board.
DA = Design assessment. The system is fully approved but not yet installed on board of a classified ship.
AiP = Approval in principle subject to a DA in a later stage.

The GTT NO96 system has evolved significantly in recent years, since it was introduced for the first time in Chantiers de l'Atlantique newbuilds in 1994 and then in Hanjin Heavy Industry-built LNG carriers in 1995. The same process has been put in place by GTT for the Mark III series installed for the first time on large LNG carriers at Samsung Heavy Industries in 2000 and in three small-scale LNG carriers built in the nineties. The figure 1 illustrates the reduction in BOR achieved by the latest Mark III Flex + and NO96 Flex systems, from 0.15% to 0.07%.

Figure 1 – The BORs achieved by GTT containment systems



Mark III Flex+ has been ordered and the first ship will be delivered in 2019.
NO96 Flex is still under development.

DEFINING THE GLOBAL ARCHITECTURE

Modelling LNG carrier design with advanced computer tools, and by studying different ship architectures and different configurations of containment systems, engines and other equipment, for one or several trade patterns, is now the recommended pathway to developing competitive LNG carrier solutions.

A computerized detailed LNG carrier model will help to select the best equipment to be installed on board by comparing different options. Different values can be compared to determine the most efficient global architecture. These may include key performance indicators such as:

- FBOG: Forced boil-off gas mass;
- NBOG: Natural boil-off gas mass;
- GCU: Boil-off gas burned in the gas combustion unit;
- Total gas consumption from all consumers (gas boilers, main engines and generator sets);
- Pilot fuel consumption in dual fuel engines.

Modern 2-stroke DF design
174,000 cu. m^3 design

Standard operating speed
19.5 knots

BOR range
0.085% to 0.105%
= 2.8 – 3.5 tons/hour

Requires approximately
10-25 tons of forced vaporisation

Solutions / realities - The Boil-off is key

But central to the research and decision-making process is the containment system BOR.

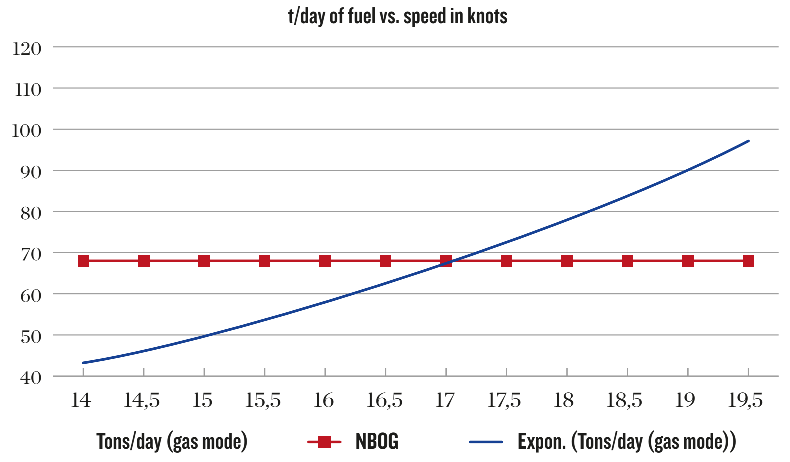
Shipbuilders involved with low BOR systems may be able to offer full re-liquefaction systems in the range of 2.5 tons per hour, which will adequately address fuel flexibility requirements, enabling a choice or combination of fuels to be used (LNG, or fuel oil or gas oil in the same ship). Of course, the re-liquefaction system may only be used in the event of unused boil-off due to low load demand during periods at anchorage, or periods of slower steaming such as canal transits.

But assuming a daily BOR of 0.085% for a modern 2-stroke DF 174,000 m^3 LNG carrier with an LNG cargo density of 0.47 tons/m^3, the amount of LNG available, either for fuel or to be re-liquefied during 24 hours in laden condition, will be in the range of 70 tons. This is the amount of LNG that would be required to achieve a reasonable, economical speed without the need for forced vaporization. If such a ship is involved in manoeuvring or low-speed operations, or is at anchorage, the excess boil-off gas will either go to a gas combustion unit or be re-liquefied. An identical scenario, but with a BOR of 0.105%, will give around 3.5 tons/hours required re-liquefaction capacity.

To achieve 19.5 knots in modern designs, with BORs ranging from 0.085% to 0.105% and 2-stroke dual fuel engines (either low- or high-pressure gas injection systems), approximately 95 tons of LNG per day will be required. Depending on the containment system, anywhere from 10 to 25 tons per day of boil-off gas will have to be forced using pumps and vaporizers.

In conclusion, there is always a balance between natural boil-off gas (given by the cargo volume and the BOR) and the ship's speed. Increased speed means a reduced total voyage duration, so all the parameters will have to be re-considered.

Figure 2 – The typical fuel consumption curve of a modern LNG carrier with 2-stroke engines (BOR 0.085%)



"Matching the continually evolving containment and propulsion systems with supporting equipment – such as re-liquefaction capability is the key challenge. Bureau Veritas helps owners find the right balance, helping them make the best decisions for both safety and efficiency."

Carlos Guerrero
Global Market Leader, Gas ships and Tankers,
Bureau Veritas

The tables 3.1 and 3.2 describe two typical modern LNG carrier designs along with their components.

Table 3.1 – 174,000 m³ LNG carrier design with Mark III Flex containment system and X-DF

BOR	0.085% V/day
Propulsion	WIN G&D - 2 x 5X72DF
	Nominal rating each: 12,500 kW @ 69 RPM
	Specific gas consumption: 144.3 g/kWh (100% power, gas mode)
	Specific pilot fuel consumption: 0.8 g/kWh (100% power, gas mode)
	Specific energy consumption: 7,249 kJ/kWh (100% power, gas mode)
	Specific diesel fuel consumption: 182.2 g/kWh (100% power, diesel mode)
	Specific energy consumption: 7,780 kJ/kWh (100% power, diesel mode)
Gensets	2 x HYUNDAI HIMSEN 8H35DF (3,840 kW @ 720 rpm)
	2 x HYUNDAI HIMSEN 6H35DF (2,880 kW @ 720 rpm)
	Specific energy consumption: 7,268 kJ/kWh (100% power, gas mode)
	Specific energy consumption: 7,814 kJ/kWh (100% power, diesel mode)
Re-liquefaction	Mixed Refrigerant 2,5 t/h
Fuel Gas	2 x 6-stage Cryostar compressors (2 x 860 kW)
	Fuel pumps (4 x 30 kW) + Vaporizers

Table 3.2 – 174,000 m³ LNG carrier design with NO96LO3+ containment system and MEGI

BOR	0.1% V/day
Propulsion	MAN B&W 2 x 5G70ME-C10.5-GI
	Nominal rating each: 12,590 kW @ 69 RPM
	Specific gas consumption: 136.3 g/kWh (100% power, gas mode)
	Specific pilot fuel consumption: 2.4 g/kWh (100% power, gas mode)
	Specific energy consumption: 6,917 kJ/kWh (100% power, gas mode)
	Specific diesel fuel consumption: 168 g/kWh (100% power, diesel mode)
	Specific energy consumption: 7,174 kJ/kWh (100% power, diesel mode)
Gensets	2 x WARTSILA 8L34DF (3,840 kW @ 720 rpm)
	2 x WARTSILA 6L34DF (2,880 kW @ 720 rpm)
	Specific energy consumption: 7,440 kJ/kWh (100% power, gas mode)
	Specific energy consumption: 7,530 kJ/kWh (100% power, diesel mode)
Re-liquefaction	Mixed Refrigerant 3,5 t/h
Fuel Gas	2 x Burckhardt Labyrinth compressors (2 x 1.480 kW)
	Fuel pumps (4 x 30 kW) + High pressure fuel pumps (2 x 180 kw) + Vaporizers

A REVIEW OF CARGO CONTAINMENT SYSTEMS TODAY

Mark III Flex +

The Mark III Flex + system is the latest evolution of the Mark III series developed by GTT. Today, HHI, HSHI and SHI are proposing this system for their standard 174,000 m^3 LNG carriers. The system comprises standard prefabricated panels made with reinforced polyurethane foam and plywood, and two different barriers, as required by the IGC Code. The primary barrier in contact with the LNG is a corrugated, thin stainless steel 1.2mm sheet, welded to support plates prefabricated in the insulation panels. The secondary barrier, which needs to be able to contain an LNG leak for a minimum of 15 days is the so-called triplex membrane, made of aluminium foil and two glass fibre covers used in two forms, rigid triplex secondary barrier prefabricated with the insulation panels and flexible secondary panels bonded to the panels at the yard during the erection of the membrane system. The low BOR of the system is achieved by increasing the thickness of the insulation from 270 mm (Mark III) to 480 mm. However, the interbarrier space situated between the two barriers is the same thickness as in the Mark III and Mark III Flex systems, so the temperature on the secondary barrier is lower than in the previous systems. The system is industrialized and presently being installed on at least one ship under construction at SHI, to be delivered in 2019.

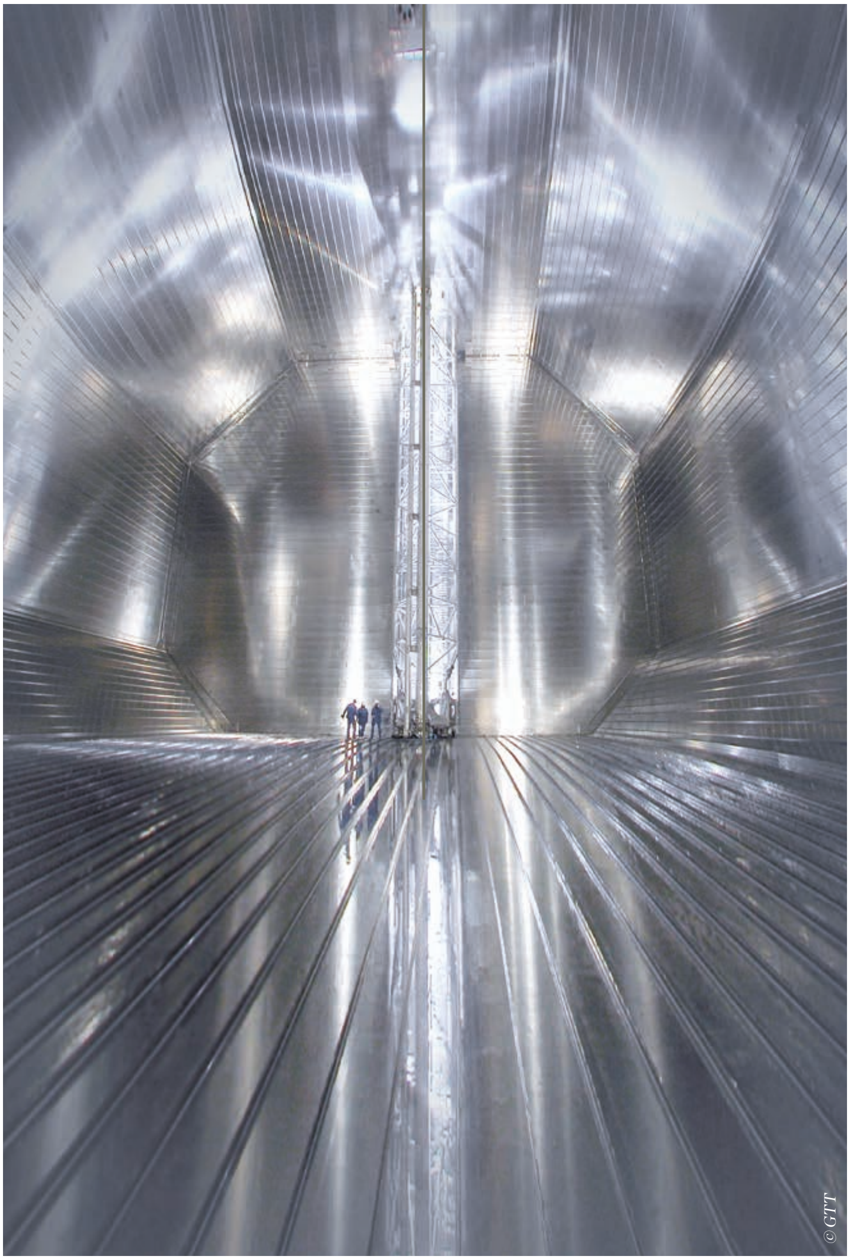
Inside a Mark III tank.

NO96 Flex

The NO96 Flex is in the process of being fully approved by BV after an AiP was developed in 2018. This new system targets the same BOR (0.07%) as the Mark III Flex +. This rate means that a standard 174,000 m^3 LNG carrier equipped with any of the two systems will produce less than 60 tons of boil-off per day. The NO96 Flex combines elements of the Mark III and NO96 technologies, as the insulation material is reinforced polyurethane foam prefabricated with plywood panels, the primary barrier is similar to the Mark III (stainless steel corrugated sheet) and the secondary barrier in between the insulation spaces is made of a very thin invar sheet (0.7 mm thickness low thermal expansion steel alloy with 36% nickel content). To achieve the very low BOR, the total thickness of this new containment system is the same as for the NO96 LO3 and LO3+ (530 mm) but the complete insulation system is made with reinforced polyurethane foam.

Withstanding sloshing

One area of development being worked on by GTT is the reinforcement of membrane systems to withstand sloshing pressures, for specific applications such as FSRUs and FSUs, LNG-FPSOs, LNG bunkering ships and LNG fuelled ships. These ship types usually have intermediate filling levels and, in some cases, the dynamic conditions of tank operations are severe, for instance during open sea navigation (LNG fuelled ships) or when station keeping in harsh environments (offshore LNG-FPSOs). Increasing the density of polyurethane foam is the standard solution in the case of the Mark III series, while for the NO96 series, additional box reinforcement is achieved by increasing the plywood thickness or adding additional internal box reinforcement. The disadvantage of having a reinforced insulation system is increased thermal conductivity, which leads to a higher BOR.



Inside a NO96 tank.

BV has been extensively involved in sloshing studies for FSRUs, LNG bunkering ships and LNG fuelled ships with different containment systems, but mainly GTT membrane containment systems. These types of application require a full range of fill levels making sloshing a more critical factor than in LNG carriers that trade with full tanks, predominantly, or a 'heel' of LNG (10% or less of the tank volume) to maintain the tanks at cryogenic temperatures and use as a fuel.

Type B systems (Moss and prismatic)

Most Moss type ships have traditionally been equipped with steam turbine technology, and only a few of them are equipped with the more recently available DFDE systems. Therefore (taking into account the link between BOR and propulsion system efficiency) insulation performance of Moss type ships has been less important than in modern ships equipped with membrane systems and 2-stroke engines. Since consumption of a steam turbine system is approximately 50% more than that of 2-stroke engines, a BOR in the range of 0.12% may be satisfactory for a Moss / steam turbine LNG carrier. However, for modern Moss ship designs equipped with DFDE engines (a small number are in service) or 2-stroke engines (under development), additional insulation thickness will be required.

MOSS type containment systems have been extensively used in applications such as LNG carrier conversions to FSRUs, FSUs and, more recently, LNG-FPSOs, as they are suitable for partial filing levels, ship to ship transfer offshore, etc, when addressing high sloshing pressures.

Structural assessment of type 'B' containment systems (MOSS or prismatic) is important, and specific crack propagation analysis is required by the regulations to allow systems to be equipped with just a partial secondary barrier instead of a full barrier (required in membrane systems, for instance) for temperatures below -55 Celsius. Structural analysis of the skirt of the spherical tanks connected to the ship's structure is also key, as is analysis of the keys or supports installed all the way around prismatic tanks.

Type C systems

Type C containment systems are commonly used in small-scale LNG carriers. They are made of single shell steel alloys with external insulation, and are independent of the ship structure. Elongation of type C tanks during thermal cycles is important, so the tanks are supported on the bottom of the cargo hold by a fixed support and a sliding support. Because type C tanks are smaller than standard 40,000 m^3 membrane tanks, the BOR increases significantly. Values of around 0.3% are commonly used for small carriers, and 0.2% for larger vessels (20,000 m^3 and above). Despite the fact that more vapours will be generated than in a large tank, for the reasons already mentioned, the advantage of type C tanks is that pressure build up is an option for boil-off management. The loading conditions at the terminal have to take into consideration the fact that at the end of the trade, tank pressure may be in the range of 4-5 bar, taking into account the heat ingress (generation of vapour). Therefore, the loading limit in a type C tank is usually reduced, as opposed to atmospheric systems (membrane or type B), which are set at a maximum of 0.7 bar.

Many other systems (see table 4) have been proposed and assessed by BV – all with different challenges to overcome. A high-manganese system, recently the subject of an IMO MSC circular, is also among the systems in the process of being assessed. Many of the new non-GTT systems assessed in recent years have been designed for small-scale applications and gas fuelled ships, but have never been considered for standard LNG carriers, except for the Moss, Type C (cylindrical, bi-lobe or tri-lobe), IHI/SPB and KC-1 systems.

Table 4 – Level of assessment achieved for systems other than GTT membrane designs

Other CCS	Type	Level
MOSS	B	BV Class Ships (FA)
CYLINDRIC/BI-LOBE/TRI-LOBE	C	BV Class Ships (FA)
IHI / SPB	B	BV Class FSRU (FA)
KOGAS / KC-1	MEMBRANE	DA
SHI / SCA	MEMBRANE	DA
DSME / ACT-IB	B	AiP January 2012
NORDIC YARDS / ADBT	B	AiP December 2011
LNT A-BOXTM	A	AiP May 2014
Lattice Technology / LPV	C	AiP April 2016
Braemar / FSP	B	AiP May 2016
Altair Engineering / CDTS	B	AiP/DA in progress
AnSwer / Bilobe High Mn	C	AiP in progress
DSME Solidus	MEMBRANE	AiP in progress

FA = Final assessment. A ship is classified and the system installed on board.
DA = Design assessment. The system is fully approved but not yet installed on board of a classified ship.
AiP = Approval in principle subject to a DA in a later stage.

BUREAU VERITAS MARINE & OFFSHORE:

FOCUSED ON LNG FROM THE VERY BEGINNING

For BV, gas has been a focus from the very beginning of its transportation by sea, and we have never stopped investing in the sector. We can look back with some pride on an industry where safety has always come first – the sector's safety track record speaks for itself. BV has achieved many classification firsts in the seaborne carriage and marine storage of LNG. In the beginning, this was, of course, partly based on the early leadership of France in LNG ship construction and design of LNG containment systems. But as leadership in commercial LNG ship construction has shifted across the globe – from Europe, to the United States, and now to Asia – BV has remained at the fore.

Proud to be at the forefront of classification in an evolving market

BV classed the first Korean-built membrane LNG carrier in 1995, the Hanjin Pyeong Taek, and the first Korean-built LNG carrier for an overseas country in 2002, the *Excalibur*. The first dual fuel diesel electric LNG carrier, *Global Energy*, was built in 2006 in France – and was BV classed. And, most recently, in a project marked by innovation, BV has jointly classed with the Russian Register the 15 icebreaking ARC 7 ships contracted to load LNG in the Russian Arctic at Yamal.

First class rules for floating gas terminals

BV recently updated and clarified its rules to provide the first set of dedicated FSRU and FSU rules. These allow for different technical and regulatory options, reflecting the main issues and questions to be addressed in floating gas terminals: conversion or newbuild; near shore or offshore location; ship or barge; storage only.

BV classed the first LNG FSRU in 2005, *Excelsior*, the first FLNG in 2013, *Tango FLNG* (Ex-*Caribbean FLNG*), and, in 2017, the largest FSRU ever built – the 263,000 m³ *MOL FSRU Challenger*. Today, the floating terminal sector market looks set to grow further including supporting the availability of small scale LNG for use as a cleaner fuel for conventional ships.

We are ready as demand for floating gas terminals grows.

For more information about floating gas terminals see our Technology Report #02.

Editorial Team
Carlos GUERRERO
BUREAU VERITAS
Capucine RIOS
BUREAU VERITAS
Becky WALTON

Chief Editor
Nick BROWN
Communications Director
BUREAU VERITAS
•
Artistic Direction
KAZOAR AGENCY

BUREAU VERITAS
MARINE & OFFSHORE
8 Cours du Triangle
92937 Paris-La Défense, France