Independent prismatic tank type A and type B for LNG and Ammonia – differences, experience, constructability and suitability

It is a misconception that an IMO Type A cargo containment system is not suitable for LNG and only used for LPG. While an IMO Type B system is for both LNG and LPG, LNG Carriers built with type B tanks have suffered serious delays and cost overruns. Type A tanks are proven as the industry standard for fully refrigerated LPG carriers and has been the workhorse of this segment for decades. This paper examines the differences between and experiences with the two containment systems when it comes to LNG and their future in the growing liquid ammonia (NH_3) trade. This paper also addresses *tank weight*, the *construction criteria and tolerance levels.* Finally, the impact these factors will have on *construction cost* will be considered.

Technology Maturity (proven experience)

The first custom-built LNG Carrier, the 27,400m^3 "Methane Princess" was in essence a type A containment system according the (later) IGC Code and had independent aluminium cargo tanks. It was developed by Conch International Methane[1] and was owned 100% by Shell. The vessel was built by Vickers Armstrong in the UK in 1964 and served the world's first commercial LNG trade between Arzew, Algeria and Canvey Island, England. The sister vessel "Methane Progress" was built by Harland and Wolff in 1964. In 1969, Esso, with its own type A vessel design, took delivery of the "Esso Brega" and "Esso Liguria" (30,000m^3) from Italian shipyards Italcantieri and Fincantieri. The vessels ended as "LNG Palmaria" and "LNG Elba", owned by SNAM of Italy and was scrapped in 2012.

The first type A LNG carrier built in 50 years, is the LNT A-BOX carrier "Saga Dawn" which was built and delivered by China Merchant Heavy Industries in January 2020 and sail with its first cargo in April 2020. The vessel is currently trading in Southeast Asia and has been renamed to "LNG Jia Xing". See more below.

Prismatic type B containment system is called "SPB" which is short for "Self-Supporting Prismatic IMO B" and was developed by Ishikawajima-Harima Heavy Industries (IHI) in Japan. IHI built the first IMO type B vessel in 1985, the 1,500 m^3 prototype carrier "Kayoh Maru", and then built the two 89,000m^3 LNGCs "Polar Eagle" and "Artic Sun" in 1993. These vessels served the Alaska (Kenai LNG) to Japan trade route and were scrapped in 2023.

The first type B LNG carrier to be built in 20 years, the 166,500m^3 "Energy Liberty" was delivered by Japan United Marine (JMU) in 2018 (and its 3 sister vessels in 2019). These 4 vessels are currently trading for Tokyo Gas. See more below.

Two 12,500m^3 tanks were ordered in 2014 at JMU for an LNG FSRU built at Wison for Exmar which was delivered in 2017.

At Wison Offshore and Marine construction of a 180,000m^3 FLNG barge for ENI's Marine XII LNG project in Congo started in early 2023. The first 47,000 (45x45x24m) aluminium cargo tank (primary

[1] LNG carrier idea was conceived by **William Wood Prince**, CEO of Union Stock Yard. Methane Pioneer (converted Normarti) (5000m3) sail with its first cargo from Lake Charles to the UK in 1959 to test if possible. Conch International Methane was a company owned by Shell 40%, Continental Oil 40%, Union Stock Yard (20%)

barrier) was assembled in July 2023. This is a cooperation between Wison and JMU with JMU providing technical support and Wison will act as fabricator at its facilities in China.

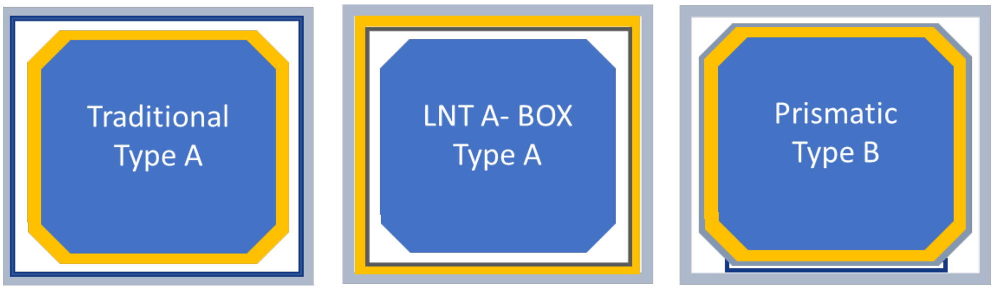
Jiangnan Shipyard (Group) has developed the BrilliancE Type-B tank, a containment system with robust prismatic nickel steel tanks. This technology has been integrated into a series of 99,000m^3 ethane carriers (VLECs) for long haul ethane and is now the world's largest ethane carriers. The yard is now looking at the application of its BrilliancE concept to an LNG tank for use on a dual-fuel large container ship under a joint research project with DNV.

In recent years, also a series of container vessels built at Hyundai Samho Heavy Industries (HSHI) has been built with IMO type B LNG fuel tanks made from 9% nickel steel. The vessels are owned by Eastern Pacific and on long-term charter to CMA CGM.

Design basis in accordance with the IGC Code

The International Maritime Organisation's (IMO) *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (the IGC Code)[2] sets the design basis and criteria for four types of cargo containment systems (tanks) allowed for transportation of liquified gases. These are independent tank types: A, B and C and the integrated tank type called Membrane. The IMO IGF Code governing ships using gases or other low-flashpoint fuels follows the same principles and criteria.

This article's focus is on the differences between prismatic tank types A and B. At first glance it is difficult to see and understand the difference between a traditional IMO Type A and a Type B.



- Independent tank with (inner) hull of low temperature steel acting as the **complete secondary barrier**.
- Ambient temperature in hold space

- Independent tank with hull in normal shipbuilding steel as a **complete secondary barrier** in front of the insulation protects the hull.
- Cargo temperature in hold space

- Independent tank with hull in normal shipbuilding steel as a **partial secondary barrier** leds a leak to drip tray for evacuation.
- Ambient temperature in hold space

Figure 1: Type A and type B containment system overview

According the IGC Code chapter 4, the goal for cargo containment is to ensure the safe containment of cargo under all design and operating conditions having regard to the nature of the cargo carried. This will include measures to:

1. provide strength to withstand defined loads;
2. maintain the cargo in a liquid state;
3. design for or protect the hull structure from low temperature exposure; and
4. prevent the ingress of water or air into the cargo containment system.

[2] The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), adopted by resolution MSC. 5(48), has been mandatory under SOLAS chapter VII since 1 July 1986.

Independent tanks are completely self-supporting and do not form part of the ship′s hull structure, as opposed to the integrated tank type. The dynamic and static loads of the cargo are transferred locally through the support system into the vessel double bottom and deck.

Type A independent tanks (primary barrier) are primarily designed using classical ship-structural analysis procedures in accordance with recognized standards. If the cargo temperature at atmospheric pressure is below -10°C, a complete secondary barrier shall be provided. (IGC Code 4.21.1). If the cargo temperature at atmospheric pressure is not below -55°C, the inner hull may act as the secondary barrier. If the cargo temperature is colder than -55°C, such as ethane, ethylene or LNG, a separate secondary barrier is required.

This means ordinary stress, fatigue and thermal calculations based on allowable stress, and insulation in combination with a complete secondary barrier that protects the hull (see below). Type A tank has been used for LPG for a very long time. What we can call a traditional type A design has mostly been used for carriage of LPG with thermal insulation on the tank surface and an inner hull of low temperature steel, normally minus 55°C, as the secondary barrier.

Arrangements to meet the design criteria of the IGC Code when it comes to LNG, must consider that LNG has a much lower temperature. The principles for designing the type A tank for LNG are similar, but need to consider the lower temperature and the thermal stress which can occur during temperature variations between top and bottom tank areas. Proper structural details and efficient spray systems will secure the tank material and stress level during cooldown and warming up.

The LNT A-BOX is containment system which has a separate insulation and secondary barrier system fitted to the hull structure that protects the hull and complies with the IGC Code as a type A cargo containment system for LNG. See figure 3 and below.

Type B independent tanks are designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. If the cargo temperature at atmospheric pressure is below -10°C, a partial secondary barrier with a small leak protection system shall be provided. (IGC Code 4.22.1)

“Cargo containment systems for which the probability for structural failures to develop into a critical state has been determined to be extremely low, but where the possibility of leakages through the primary barrier cannot be excluded, shall be equipped with a partial secondary barrier and small leak protection system capable of safely handling and disposing of the leakages.” (IGC Code 4.4.3) “Where the size of the secondary barrier is reduced, as is provided for in 4.4.3, fracture mechanics analyses of fatigue crack growth shall be carried out…” (IGC Code 4.18.2.6.1)

This means advanced and precise engineering studies, including strength analysis and laboratory tests. (See below)

Type A LNT A-BOX system is based on proven technologies, but in a novel patent-protected configuration. The design is based on an independent tank type A as the primary barrier and a full secondary barrier. Design and construction of type A tanks is based on classical ship structural principles and is reasonable to build. In addition, the tank is flexible in shape and geometry, catering for excellent volume utilisation, while internal structure mitigates sloshing and eliminates any loading limitations.

The tank itself is not insulated but is installed in an insulated hold space like a cold box. This means that the insulation is attached to the interior surface of the hold, while a liquid tight barrier is fitted on the inner surface of the insulation acting as the secondary barrier. In between the tank and the secondary barrier is a cold inter-barrier space, which offers direct access for visual inspections and maintenance of both barriers as well as the tank supports.

Protective Distances

Fittingly the first major feature in the IGC Code address s*hip survival capability and location of the cargo tanks* (chapter 2). It stipulates a minimum (protective) distance between the sea and the cargo. This distance is identical for the two independent prismatic tank types (A and B), and the IGC Code does in fact not distinguish between the two.

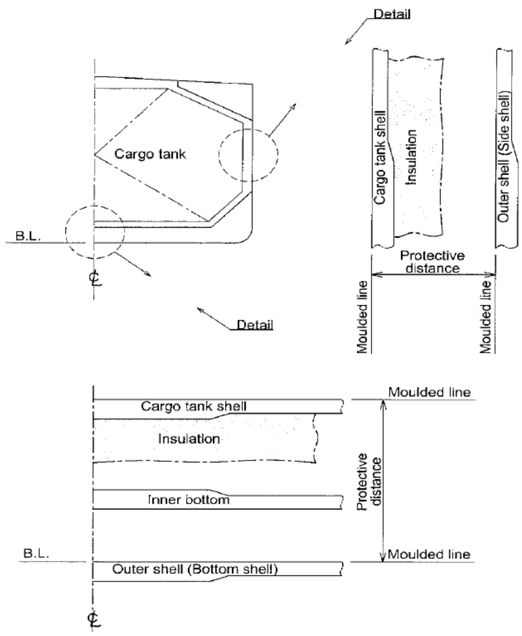


Figure 2: IGC Code figure 2.5(a) Independent prismatic tank - Protective distance

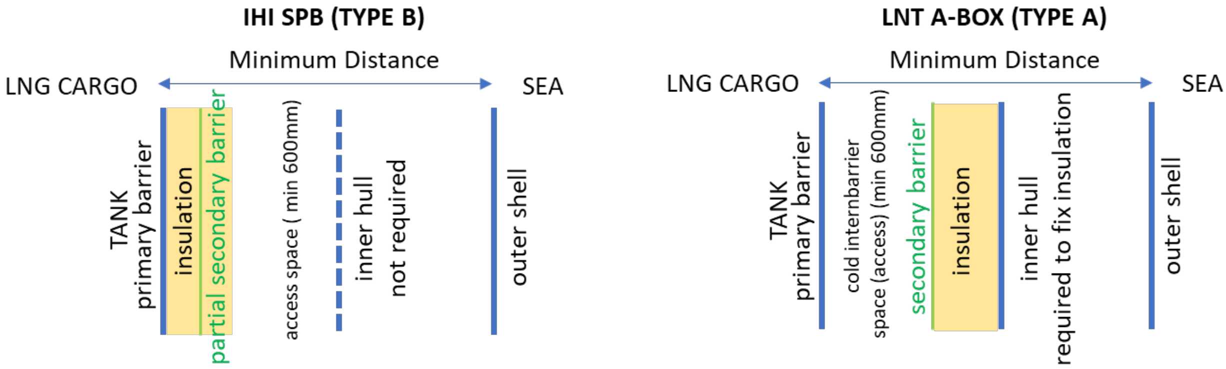


Figure 3: Configuration and Protective Distances (Side Shell) Type B and Type A LNT A-BOX

Volume Efficiency

Even though the two prismatic tank types A and B have the same criteria for hull volume utilization (the protective distance addressed above), it appears that the hull volume of the 166,500m^3 capacity type B vessel "Energy Liberty" (delivered in 2019) is not optimally utilised compared to the 174,000m^3 LNT A-BOX vessel (yet to be constructed). See the comparison table below. Dimensions of the vessels are similar but the LNT A-BOX vessel carrying capacity is higher. Gross tonnage for the "Energy Liberty" gross tonnage (GT) is 121,982 tons compared to 109,850 tons for the latter. The heavier, the more under-utilised is the hull space. The dead weight ton (DWT) to cargo capacity comparison giving a cargo density of 0.53 and 0.45, respectively (LNG density normally at 0.45 ton LNG to water). Is the "Energy Liberty" designed for a heavier cargo or are there other factors that makes its hull less optimally utilised, for example need for ballast in cargo conditions, weight and COG ref stability, special terminal requirements etc.?

Large scale LNG carriers

Parameter	Unit	LNT174	Energy Liberty	DSME/GTT	SHI/GTT
Containment system	[-]	LNT A-BOX®	IHI SPB	GTT NO96	GTT Mark III Flex
Cargo capacity	[m3]	176,400	166,571	173,400	174,000
Loa	[m]	294.5	299.9	294.9	293.2
Lpp	[m]	290.0	..	282.9	285.0
Beam	[m]	45.8	48.9	46.4	45.8
Depth	[m]	26.5	26.4	26.5	26.2
Design draught	[m]	11.5	12.3	12.5	12.0
DWT design	[ton]	80,000	88,676	95,803	88,684
Gross tonnage	[-]	109,850	121,982	113,049	115,174
BOR	[%]	0.07	0.08	0.075	0.085
Service speed	[knots]	19.5	19.5	19.5	19.5
Propulsion power	[kW]	25,000	25,000	24,000	25,000

Figure 4: Large Scale LNG Carriers comparison table

Boil Off Rate

To determine boil-off rate from the cargo, the IGC Code boundary conditions are:

- Sea water temperature 32°C
- Air temperature 45°C
- Cargo temperature –162°C
- Cargo density 430 kg/m3
- Latent heat of cargo 511 kJ/kg

Both type A and type B can be designed with insulation thickness which can achieve optimal Boil-Off Rate (BOR). Since the insulation is not exposed to any static or dynamic loads from the cargo, the insulation material is optimised for thermal performance which means that both systems can offer market leading boil-off rates.

One advantages for the type A containment is the cold interbarrier space. The access space between tank and insulation (600 mm) contain nitrogen in operation and have a temperature similar to the cargo. This space will have an insulation effect and will improve the BOR. On B tanks the space has ambient temperature.

BOR at 0.08% is specified for the 166,500m^3 SPB vessels delivered in 2018/2019.

For the LNT A-BOX 175,000m^3 carrier, the design BOR, with insulation thickness of 400mm, is 0.075%.

Insulation System Fixture and Secondary Barrier Functionality

For the SPB system, polyurethane (PUF) insulation panels are *secured to the tank* by studs. There is space between the tank and the insulation panels to provide space for gas detection and liquid passage to the drip tray at the bottom of the tank if a cargo leak should occur. Each PUF panel incorporates partial secondary barrier and acts as a splash barrier.

For the LNT A-BOX system the PUF panels are *secured to the inner hull* by a single stud bolt and then covered by a complete secondary barrier of reinforced aluminium foil. In the unlikely event of a leak, the liquid tight secondary barrier is designed to hold the full liquid gas inside the containment system for 14 days.

Because the SPB have a partial secondary barrier only, the tank must be designed and built to prevent a crack from propagating to a full collapse, hence its fatigue strength tolerances must be closely measured and followed, and the tank must be constructed accordingly. See more below on tolerances and quality control.

In case of a leak, the insulation on the SPB tank will be under pressure pushing the panels away from its fixture on the tank, i.e. tension on the stud bolts, panels and splash barrier. Securing the panels in place is of high importance. For the LNT A-BOX it will be the opposite with the insulation being pushed towards the inner hull with compression forces and thus its fixture can be simpler and easy to achieve.

Shipyard Installation Ability

From a shipyard perspective, it is a principal advantage that the containment system is a separate package for installation into the vessel. This can be achieved with both SPB and LNT A-BOX. The containment system would thus not interfere with the actual shipbuilding process before they are ready to be installed. The shipyard would in essence only prepare the tank support system before the tanks are fitted. Furthermore, the tanks can be constructed concurrently and separately either at the yard itself or at another manufacturer. The tank and insulation fabrication can be seen as risks that can be shared between the shipyard and containment system supplier. Type B or SPB containment system – the tank/primary barrier and the insulation incorporating the secondary barrier – are built separately and delivered as a complete package. Type A LNT A-BOX system are delivered with top and bottom insulation (and secondary barrier) and support system first, followed by the uninsulated tank and then completed with hull side insulation (and secondary barrier). The advantage of the LNT A-BOX system is that the uninsulated tanks are simpler and faster to build and the weather deck can be closed before the hull side insulation (and secondary barrier) are installed. Work to complete piping and equipment on deck can be carried out concurrently with the installation below deck. The deck of an SPB carrier cannot be installed before the complete tank with insulation is installed.

Type A tanks are based on classical ship structural design and construction methods, making them simplest to design and build in comparison to other IMO IGC Code tanks. It is therefore relatively straightforward for most shipbuilders to build a type A tank. It therefore differs from other containment systems regarding construction friendlessness. The primary goal with the LNT A-BOX system is to enable a greater range of shipyards to enter the LNG sector. Due to easy fabrication and a relatively simple insulation system, even shipyards without previous experience of gas carrier construction should be able to build LNG carriers with this containment system This was proven in practise with the Saga Dawn project at China Merchant Heavy Industry (CMHI), which had never built gas carriers before.

SPB containment system construction experience

As mentioned above, 20 years after the first major SPB LNG carriers were built, four (4) 166,500m^3 LNG carriers (each with 4 tanks of about 40,000m^3) were ordered in 2014 by Tokyo Gas at Japan Marine United (JMU)[3]. The vessels were originally scheduled for delivery in mid-2017. However, the building did not go according to plan as can be seen from the following quotes from Tradewinds:

"*The volume of material and the handling required for the fitting of the SPB system has taken longer than originally expected*" and "*The work proved more expensive than earlier estimates*" (TW 28.10.2017)

[3] JMU is a merger of IHI shipbuilding and Universal Shipbuilding

“*Shipyard officials have said the construction process for the tank containment systems had proved complex*”. And “*…. that fitting the insulation panels on the vessels’ tanks had proven difficult”* (TW 18.02.2018)

“*… increasing the workforce had not solved the problem*” and “*we just can’t seem to improve construction efficiency*” (TW 09.02.2018)

“*The revival of SPB tank construction has largely caused the delay and headache for JMU on these vessels*” (TW 24.05.2018)

“*Once the vessel [“Energy Liberty”] has been delivered, three sister vessels are scheduled to follow at 4-months intervals.*” (TW 08.09.2018)

The tanks were built at Imabari Shipbuilding’s Saijo Shipyard. Each newbuilding hull was towed from JMU’s Tsu facility for tank installation then towed back for final outfitting.

Exceptional losses of $842m were declared in April 2018 by shareholders (JFE Holdings and IHI Corp) in relation JMU which is largely attributed to the tank problems encountered on fitting out the 4 vessels. “Energy Liberty” which eventually was delivered in October 2018, after being scheduled for delivery in July 2018 and originally in mid-2017, suffered a 16-month delay. No. 2 was delivered in Feb 2019, No.3 and 4 in Q2 and Q3 2019 respectively.

Based on the above media reports, it seems reasonable to say that if IHI, the original shipbuilder, encountered these massive tank newbuilding problems, delivery delays and as a result huge cost overruns, any new shipyard with no experience with type B LNG carrier construction should be very uncomfortable to take on a type B LNG carrier project.

LNT A-BOX containment system construction experience

While only a single LNT A-BOX carrier has been constructed and it is a long time since a type A containment system has been used for LNG, the containment system is proven technology. The construction of the 45,000m^3 “Saga Dawn” prototype has provided experience and feedback (lessons learned).

Shanghai Merchant Ship Design and Research Institute (SDARI) has scaled up the LNT A-BOX system to an Atlantic max size of 175,000m3 LNGC, with American Bureau of Shipping (ABS) granting the design an approval in principle and it is also approved by Bureau Veritas (BV) and China Classification Society (CCS).

A thorough 6-months technical assessment program and analysis of the new large scale carrier design by a third-party engineering firm has concluded that the new LNT A-BOX design is technically sound and constructable and meets all requirements expected of a large-scale LNG carrier.

As LNT A-BOX tank manufacturer, China First Heavy Industries (CFHI) Dalian Nuclear Power and Petrochemical Company has been qualified. CFHI is a large manufacturer of nuclear reactors as well as pressure vessels for the petrochemical industry. At their factory in Dalian, China, CFHI has built a mock-up of a 3D corner of the tank (in aluminium) with representative details for a mid-ship tank to hold 45,000m^3. The mock-up has been used for verification and qualification and demonstrates design principles and constructability. CFHI can supply tanks for LNT A-BOX type carriers for all types of liquid gases including LNG, LEG and Ammonia (NH_3).

Tank Weight and Construction Hours

Actual references indicate that a type B tank is in the range of 20%-35% heavier than type A tank if we compare the aluminum tank only (see graph below). This means that an SPB tank requires about 400 tons more aluminium per tank than an LNT A-BOX tank, giving a higher material cost alone of about $ 4 million (aluminium price of 2,380 USD/t) if we consider a 174,000m^3 LNG carrier size comparison.

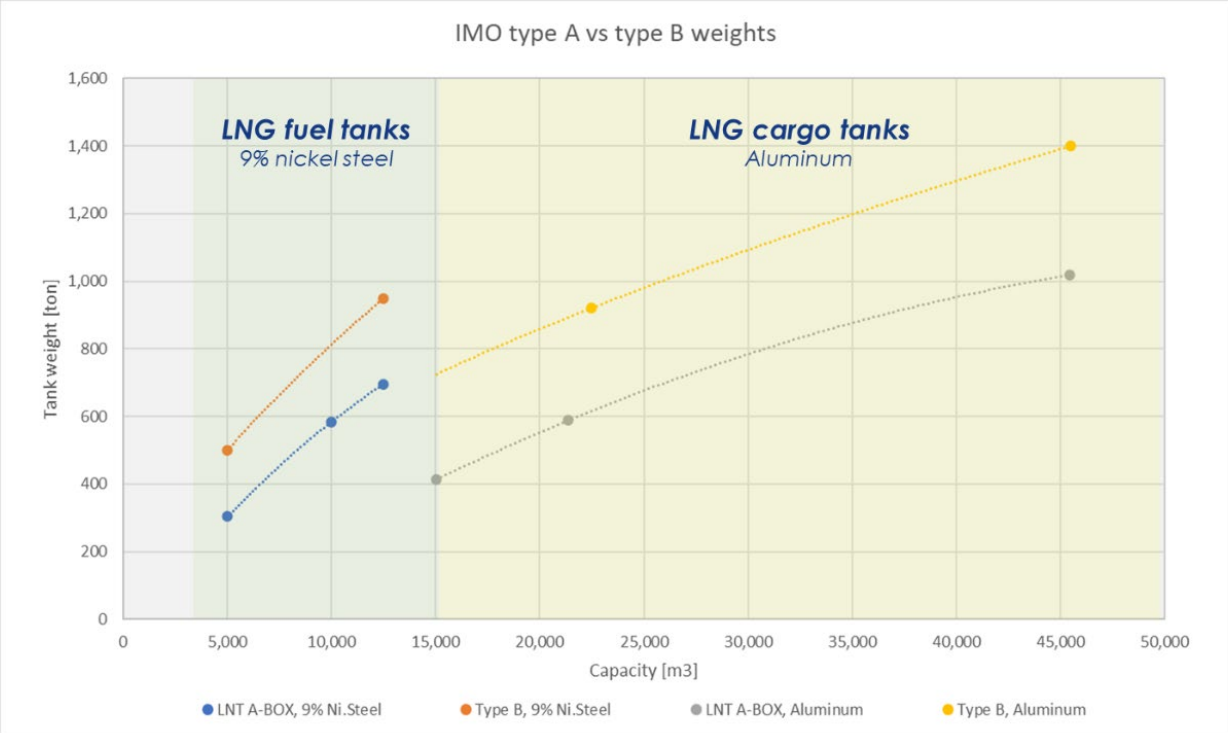


Figure 5: Comparison of tank weights between Type A and Type B

Construction work hours for an SPB tank are higher because of stricter design criteria and not the least the demanding welding, workmanship and QC requirements, which also leads to more emphasis on constructability than weight optimization (which is why this translates into the need for higher margins and thus selection of heavier/thicker materials, profiles, etc. be it steel or aluminum).

Construction Tolerances - tank welding, production techniques, workmanship and quality control

The requirements for tank welding, production techniques, workmanship and quality control are distinctly different between the systems with type A requiring ordinary shipbuilding standards and requirements, while type B requirements are very demanding and perhaps beyond what many shipyards can manage:

For type A: A standard in accordance with hull standard (IACS R47). Normal requirement for workmanship. Limits for imperfections for quality levels: B (ISO 5817) Manual welding techniques apply. Automated /robot production may be considered, but not required. Radio graphic (X-ray) tests, Ultra-sonic testing, and Dye penetrating testing. X-ray for all welded joint on tank skin/shell plate.

For type B: Strict requirements on workmanship to justify adequacy of fatigue inputs in analysis. Limits for imperfections for quality levels: B (ISO 5817) including additional requirements for welds subjected to fatigue, such as weld bead toe radius and flange angle. Special automatic/robot welding techniques apply. Controlled welding conditions. Bead dressing. Uniform high quality weld beads in accordance with weld requirements justifying Kt > 3 requires high degree of welding skills and time, which may offer construction feasibility risk. Radio graphic (X-ray) tests, Ultra-sonic testing, and Dye penetrant testing. Control of weld bead shape including toe radius, flange angle, bead height and length with pencil type sensor. X-ray for all welded joints of tank skin/shell plate and all welded joints of face plates of main girders.

Sloshing and Flat Weather Deck

Independent prismatic type A and type B cargo tanks (the tank itself) are similar in design. The tanks are designed with internal structure, i.e. web frames, girders, stringers and longitudinal stiffeners. The two tank types will typically be designed with an open centerline bulkhead and open transverse bulkhead(s) both acting as swash bulkheads. Related to internal structure and swash bulkheads, liquid sloshing is not an issue and the IGC code thus allows cargo loading and carriage at any level.

Both tank designs also make the weather deck flat with ample space to allow installation of equipment and process modules. Combining these two factors makes both tank types ideal for use as a floating import receiving terminal (FSRUs) and offshore LNG production (FLNG) units.

Ammonia Shipping

Most of the 18-20 million tons of ammonia that is traded by ships today, are transported on Large Gas Carriers (LGC) and Medium Gas Carriers (MGC). About 40 ships are employed in the ammonia trade today.

Ammonia will emerge as a key energy carrier and shipping fuel if the industry is to hit its increasingly difficult target of reaching net zero emissions by 2050.

The use of ammonia in shipping will therefore increase dramatically over the next two decades to grab a 44% share of the shipping market under the ambitious timeline, according to an International Energy Agency (IEA) report.

All types of IMO IGC Code tanks can according to the IGC code be used for transportation of ammonia. In practice however only type A and C are used for this purpose.

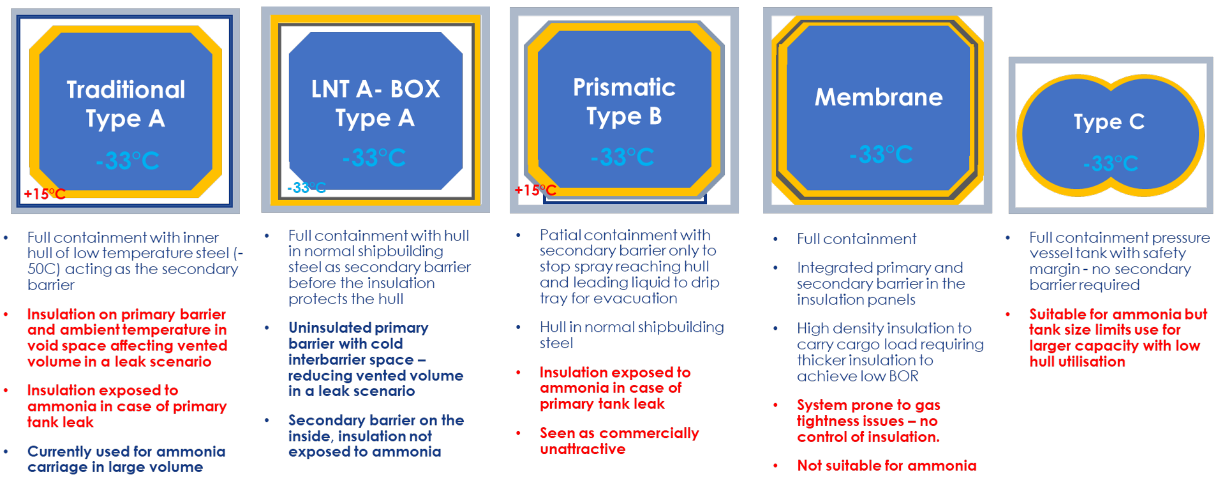


Figure 6: Comparison of containment systems for large scale carriage of Ammonia

Ammonia is typically transported in LGCs designed for ammonia transportation with IMO tank Type A.

Due to compatibility issues between NH_3 and typical insulation materials such as polyurethane, there are technical questions as to its suitability of type B tanks to transport ammonia because in a leak scenario liquid ammonia will damage the insulation and thereby the integrity of the splash barrier/spray shield. Furthermore, potential leaks via the drip tray at ambient temperature will give emission control issues of the toxic gas. Few if any type B carriers are used for ammonia transportation. For commercial reasons a type B carrier has also not been attractive for LPG transport. Type B is also no longer commercially attractive for large LNGCs)

Not all LPG carriers with traditional type A may be used due to corrosivity (secondary barrier material), toxicity (venting) and reactivity with insulation in the same way as type B.

Furthermore, the IMO IGC code chapter 4, 6 and Appendix 4 outlines specific requirements for thermal insulation and other materials used in the cargo containment systems to ensure that they are adequate for the intended service. In appendix 4, 4.1.3 it is stated as follows:

Materials should be selected according to their intended use. They should:

.1 be compatible with all the products that may be carried;

.2 not be contaminated by any cargo nor react with it;

.3 not have any characteristics or properties affected by the cargo; and

.4 be capable to withstand thermal shocks within the operating temperature range.

LNT A-BOX is the only system where the insulation is on the outside of the secondary barrier, thus not exposing the insulation to ammonia in a leak scenario. Moreover, the cold interbarrier space is a closed and controlled space with temperature close to the cargo temperature, and as such the vaporization is limited and venting through the safety valve can be controlled.

Type B: Highly questionable. Since a crack potentially can occur, the thermal insulation fitted to the tank can be exposed to ammonia leaks and must therefore comply with the requirements above. Polyurethane foam, which is the most efficient and common insulation material, is not compatible with NH3 and not suitable for this application.

Membrane: Is not suitable. The integrated tank and insulation are prone to tightness issues and thus it is also exposed to NH_3 degradation in a gas vapour or liquid leak scenario.

Type C: Not suitable in larger size. For small tankers <10k and bunker vessels, but for bunker vessel a higher risk than atmospheric tanks have been identified in a class study (LR).

When looking for future -proof solutions LNT A-BOX seems the most attractive system suitable for LNG now and ready for LNH_3 in the coming decades.

------- END OF PAPER-------

LNT Marine

LNT Marine (LNT) is a technology and service provider within the maritime industry specialized within liquefied gas tank systems and cryogenic insulation. The company provides design and engineering for marine solutions based on proprietary energy efficient technologies and offer system supply as well as technical support and installation services. LNT's proprietary technologies includes the award-winning LNT A-BOX® containment system, ammonia-ready LNG fuel tank systems and spray foam insulation systems for various types of gas carriers and fuel tanks.

For more information please visit www.lntmarine.com and follow us on LinkedIn.

