GST, A NEW GENERATION OF LNG MEMBRANE-TYPE LAND STORAGE TANK

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ABSTRACT

Under current market conditions, the surge in the demand for new LNG facilities or for readily available increased storage capacity, as well as the rising cost of raw materials make the selection of membrane-type containment systems more and more attractive for LNG land storage. In this context, GTT (Gaztransport & Technigaz) has leant its extensive expertise of membrane containment systems both for LNG carriers and for land storage, to develop GST® (1), which is the new version of the double membrane solution dedicated to on-shore and off-shore storage.

In the first part of this paper, the main characteristics of GST® will be presented. After a description of the components and their functions, the building process and its suitability to meet the highest safety and reliability standards will be described. The innovations of GST® compared to the former membrane-type concept will also be high-lighted.

A significant improvement consists in an exclusive simplified modular structure, requiring only a few different elements of a similar type as those used for Mark III LNG carriers. The underlying principles of this new design and its main advantages will be examined: a significant cost reduction and time for erection gained through an extensive use of automated devices for the installation of the elements on site, as well as a high level of standardisation during the production of these elements.

A second part will then describe the secondary barrier integrated to the insulation panel which protects the concrete walls and the bottom of the tank.

Finally, the suitability of GST® for very large storage tank capacities will be demonstrated, and current on-going projects with this system will be outlined.

(1) GST: GazStorage & Technigaz

INTRODUCTION

As energy demand constantly grows and energy storage becomes more and more crucial, LNG appears as one of the most interesting solutions, because of its ratio of volume over energetic capacity. Indeed, energy demand is such that the existing gas storage capacity under its gaseous form is no longer sufficient to meet these growing needs.

But LNG storage will have to adapt to the new market conditions. To face extensive needs, strategic storage becomes a necessity, and particularly in countries with very high population density where glaring shortages of energy appear regularly. For example, the frigid Siberian cold front that China met no later than January 2010 caused dramatic shortages of energy, with lack of coal supply, fuel shortages and power outages to a large part of the country. During the same extremely cold season, Pakistan had to cope with long power cuts of between 15 to 16 hours or even 5 days without electricity, and a lack of natural gas that made life miserable for Pakistanis. This situation throws light on the catastrophic energy crisis that Pakistan is facing. And even in Europe, Britain has known the first widespread blackouts since the 1970s because of looming energy shortages. Supply of electricity failed to meet demand at peak times. Other countries are also facing the same energy shortages during their summer peak season. Brazil or India for instance, have to deal with important power shortages during the peak hours of their hot season. These examples, among many others, justify the concerns of the energy companies as well as the different governments about the need for more and more strategic storage and the multiplication of peak-shaving facilities.

In addition, LNG price variations and the scattering of the different gas sources lead to the need for further storage capacities. As a consequence, more storage tanks with bigger capacities will be built and mainly in countries such as the ones mentioned above, but also in countries showing a growing interest in environmental aspects, LNG being considered as a “clean energy”.

Storage can be installed on-shore or offshore and the decision about the choice of the site is governed by economical, political, environmental, strategic considerations. Whatever the choice, the same technology is suitable for both solutions, on-shore and offshore. Indeed, the LNG membrane type containment system is applicable to any kind of vessel as well as to land storage.

Lastly, the Industries is constantly looking for innovative solutions, aiming at reducing construction schedules and being more cost effective. The purpose of this paper is to show how the GST® Membrane design is of particular relevance, in the context of the LNG industry’s continuous quest for larger and larger capacity storage tanks and answering to those main concerns of building time and cost reduction.

THE MAIN CHARACTERISTICS OF GST® MEMBRANE TECHNOLOGY

The “inheritance”

As a “New Generation”, GST® has some ascendants, and important ones at that, to rely on.

Today, there exists a large number of land-based membrane design storage tanks, of varying capacities, in or above-ground. The largest capacity tanks ever built are membrane design in-ground tanks.

Among these land-based tanks, 29 were built with the TGZ (Technigaz) design. The two first ones -120 000 m3- have been in successful operation for Gaz de France since 1981, in Montoir-de-Bretagne. Following those, 10 X 100 000 m3 - were built for KOGAS in Pyeong Taek, South Korea.

In addition to the 29 land-based tanks, the Technigaz membrane concept, MARK III, is used on more than a hundred LNG carriers, successfully operating. The oldest one still in service turned forty years old in 2009.

Moreover, this technology has been approved by the major Classification Societies, the biggest shipyards (Samsung HI, Hyundai HI, Imabari, Hanjin…) and the Major Oil & Gas Companies (BG, SHELL, EXXONMOBIL, MISC…).

Figure 1. The two first membrane tanks at Montoir-de-Bretagne

The basic concepts of the GST® technology

The separation of the main functions

The GST® concept is first of all, based on **a clear separation of the main functions**. This way, the **structural function** is ensured by an outer post tensioned concrete tank, which grants structural resistance to the inner hydrostatic load and outer hazards.

The **tightness function** is provided by a primary corrugated stainless steel membrane which is liquid and gas tight. The membrane is tightly welded to the carbon steel liner on the inner side of the dome roof and therefore ensures a total gas tightness of the containment system. In addition, a moisture barrier applied to the inner surface of the concrete structure prevents any water migration from the concrete to the insulation space.

The **insulating function** is ensured by “load bearing” reienforced PUF insulating panels, secured onto the concrete wall with anchoring elements (mastic and studs), and permanently maintained under nitrogen atmosphere. The monitoring of the insulation space allows the detection of any possible primary barrier leak. Finally, an insulated suspended deck maintains the roof at an acceptable temperature. The thickness of the insulation depends on the required daily boil off rate, typically 0.05%.

This separation of the main functions allows the optimization of each function, permitting individual and global testing and avoids simultaneous multiple failures. This enhances **the reliability and efficiency of the membrane system.**

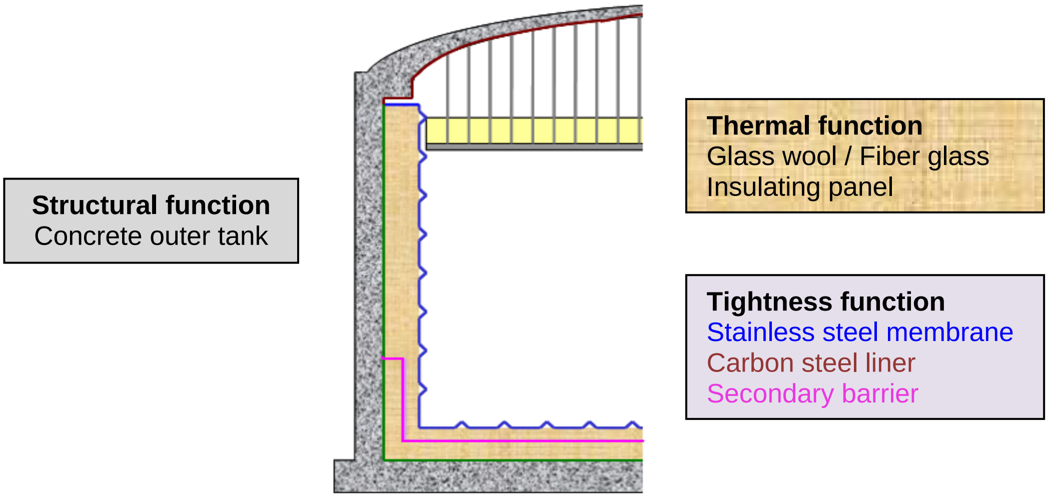


Figure 2. Overview: Separation of main functions

Description of the Membrane Containment System Components

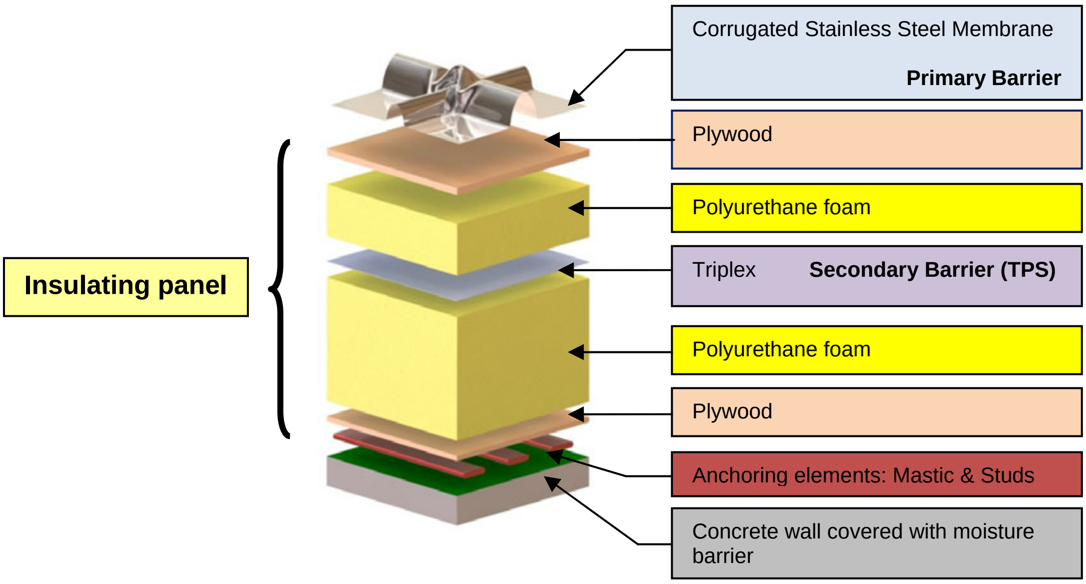


Figure 3. Overview: Containment System Components

The Primary Membrane: this corrugated stainless steel membrane (304 L) is 1.2 mm thick. The orthogonal corrugations allow free contractions or expansions, in both directions, under thermal solicitations. This makes the membrane insensitive to thermal loads or potential soil and structural deflection. The primary membrane is constituted by standard pre-fabricated membrane sheets, welded onto the insulating panels and lap welded over each other.

Two main types of elements (Figure 4) are required to pave the inner side of the tank:

- Rectangular sheets (3 x 1 m) are used for the walls and 80% of the bottom.
- Triangular Junction sheets are used to cover 20% of the bottom.

Special pieces are also needed to terminate the corrugations and in corners and angles.

The stainless steel membrane is anchored and tightly welded onto the top of the tank wall (upper insert). The space behind the primary membrane is called the primary insulation space. It is kept under neutral atmosphere which allows permanent control of the integrity of the inner containment by gas analysis.

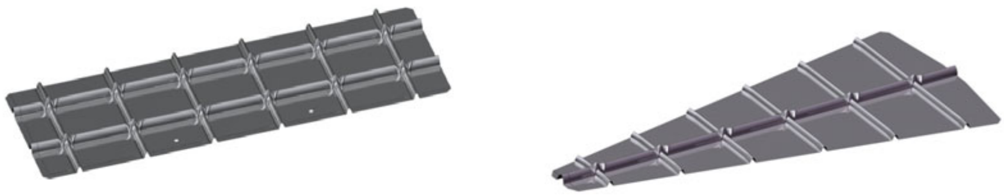


Figure 4. Primary membrane main elements

The insulation panels: the bottom and the inner walls of the tank are paved with pre-fabricated insulating panels, once the moisture barrier has been applied on the concrete and the hydro-test performed. The insulating panels are a "sandwich type" (see Figure 3 above), made of reinforced polyurethane foam inserted between two layers of plywood. The insulating panels come in three different shapes depending on their location: flat panels, corner panels or trihedral panels.

The panels are secured on the inner side of the concrete with mastic ropes and kept in place by studs. The density of the polyurethane foam is selected according to the pressure loads that will be sustained and the thickness of the insulating panels is defined by the daily boil off rate required. This insulating structure transmits the hydrostatic load to the concrete.

Stainless steel anchoring elements are inserted on the top plywood layer during the pre-fabrication of the panels, and are dedicated to the fastening of the membrane.

Standard panel with TPS | Standard panel above TPS

Figure 5. Standard and modular insulation panels

The secondary barrier: the secondary barrier is a composite material which consists of an aluminum sheet inserted between two layers of woven fiber glass. Under its rigid form (RSB: Rigid Secondary Barrier), this barrier is incorporated into the insulating panels at the prefabrication stage. Tightness between adjacent panels is ensured by bonding strips of this flexible material (FSB: Flexible secondary Barrier) over the joints.

In the case of a primary barrier leak, the secondary membrane ensures liquid tightness. This protects the concrete corner up to a height of about 5m, against low temperatures. This protection allows the system to be shut down safely (and decommissioned if necessary). Together, the secondary membrane and the related insulation are called “Thermal Protection System” (**TPS**).

This secondary membrane is anchored on the wall at its top through a peripheral insert (lower insert) as shown on the next figure 6.

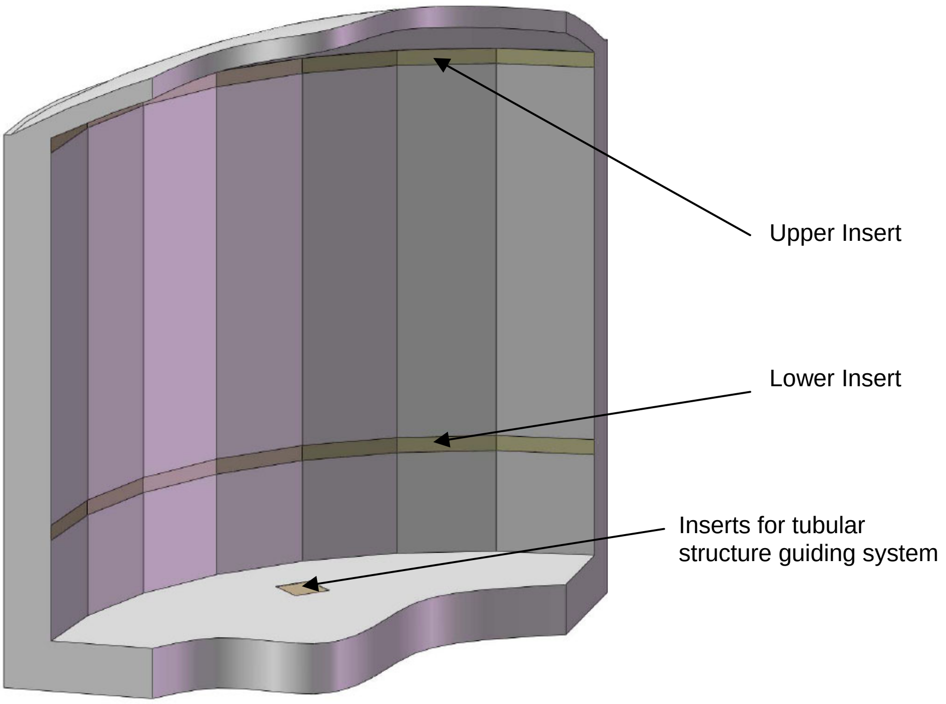


Figure 6. Overview of the different inserts

Anchoring elements: there are two types of anchoring elements:

- 2 horizontal inserts are anchored into the concrete structure to close primary and secondary membranes. A third one is used to fix the pump tower guiding system.
- Load bearing mastic and studs that fasten the insulating panels onto the concrete wall. These anchoring devices ensure an even load transfer between the containment system and the concrete container.

The load bearing mastic also helps to compensate for any potential deflection of the walls. As for the studs, they are used to position and secure the insulating panels during the curing of the mastic.

Moisture barrier: a polymeric component made out of epoxy and glass cloth, is applied on the inner face of the concrete structure, in order to prevent liquid or vapor ingress from the concrete to the insulation space at any time. It also has the advantage of compensating for possible hair cracks in the concrete. Its thickness is about 3 mm.

The double barrier protection

In addition to the stainless steel membrane, the secondary barrier as described above is inserted in the insulating panels at the pre-fabrication stage. In the event of a failure of the primary barrier, the secondary membrane ensures the liquid tightness and will protect the concrete wall, preventing stress concentration on the concrete corner, as required by European standards, namely EN 14620. Thanks to this TPS, the GST® membrane tank complies with the same functional requirements as the 9% Ni type full containment tank.

RELIABILITY AND SAFETY

Reliability

The reliability of the GST® membrane system is firstly proven by its “inheritance”. More than a hundred LNG carriers equipped with MARK III type containment systems have been successfully operating for over 40 years. Secondly, 29 land-based storage tanks are now in service, the first of which was built 30 years ago.

Terminals owners equipped with Technigaz storage tanks have clearly expressed their satisfaction in different couriers. For examples:

- **KOGAS**: “We, KOGAS, are pleased to inform you that Above Ground Membrane Tanks in Pyeong Taek LNG Terminal have been well operated for over 20 years without any problems even though LNG filling temperature to tank was under -140 Celsius degree. We understand that SN TGZ designed the tank taking into consideration of high standard of safety, reliability and endurance.”

- **GAZ DE FRANCE**: “…ELENGY has not made any maintenance on the inner primary tank of its membrane tanks…. Concerning the membrane no maintenance / alteration / modification was needed nor performed as no disorder was stated. As we speak, our tanks will be kept on operation till 2035 and no inspection is planned.”

- **TOKYO GAS:** “We constructed underground LNG storage tank with NKK's membrane under license of TGZ in 1984…. This tank has been operated safely since commissioned. We have not de-commissioned this tank for an inspection, and we have no plan for de-commission. We design and construct the underground LNG storage tanks which don't require the inspection for membrane within design life. In addition, we verify the residual life for membrane based on the actual pressure change and liquid level change. We confirmed that we can continue operation for a couple of hundred years.”

Beside those expressions of satisfaction, only two incidents on Technigaz tanks were reported. These incidents never involved the containment system itself, were minor and never occurred in normal operation (only during the start-up phase). They are described in the following table 1.

Table 1. List of incidents on TGZ land-based tanks

Terminal site	Pyeong Taek (Korea) Tank n°3	Pyeong Taek Tank n°10
Type of the tank	Above-ground TGZ	Above-ground TGZ
Client	KOGAS	KOGAS
Tank capacity	100 000 m3	100 000 m3
Commissioning year	1986	1998
Time of incident detection	At start-up	At start-up
Cause & Comment	A metallic piece of the dome has been damaged by an arc welding machine. The membrane was not involved	Several leak test holes were not plugged properly before the cooling-down. The membrane was not involved.

Materials quality

GTT provides the storage tank EPC contractor with the specifications for material and prefabricated elements, as well as a list of suppliers which have been approved for a certain component. This generic document provides guidelines to assist all concerned parties with a view to gaining a better understanding of GTT functional specifications and their use in the approval of components (material and prefabricated elements) for LNG land-based storage tank containment system construction.

Its purpose is to better clarify the role of each party involved (in particular in relation to quality processes during approval and production). Any company wishing to obtain approval for its component and become a recognized approved Supplier must make a request in writing to GTT. When deemed necessary and consequent to satisfactory review of general information concerning the requesting company (such as the industrial capacity of the company to meet an order for a GST® containment construction), GTT shall launch the approval process. The approval process for an industrially manufactured component shall be in accordance with its associated functional specification.

It is the responsibility of Supplier using dedicated quality & production processes to ensure a continued fidelity & repeatability of the approved component. It is the responsibility of EPC contractor (client) to control the quality level of components supplied before use in GST® containment system erection.

Tests

GTT's successful experience with regards to membrane containment systems is due to a rigorous control program throughout the erection of the tank. From the end of the concrete structure construction to the end of the containment system erection, numerous tests are carried out. The main tests are mentioned below.

- Hydro-test, as specified in the EN 14620-5 Standards, § 4.1.2.
  It is to be noted that, in the case of a 9% Ni type Full containment, there is no hydro-test performed at this early stage, i.e. before the containment system erection.

- Vacuum box test, to check the TPS tightness.

- NH_3 (ammonia) test, to check membrane welds tightness.

- Global test, to check the global tightness of the containment system.

An efficient monitoring process

The membrane is tightly connected with the steel dome liner, in such a way that **the insulation space constitutes a closed cell**. The insulation spaces, behind the primary membrane and behind the TPS, are continuously under nitrogen atmosphere and monitored to detect potential accumulation of Natural Gas.

The purpose of this monitoring system is to ensure a permanent control of insulation spaces by gas analysis and temperature monitoring. In the case of gas or cold spot detection, the gas concentration is lowered by nitrogen sweeping.

This monitoring system includes:

- Temperature sensors, installed in the insulation space behind the primary barrier, on the TPS and on the concrete structure (bottom and walls);

- Pipes/tubes allowing Nitrogen distribution at the top / bottom of the tank and located in the insulation spaces;

- Gas sampling nozzles, controlling the gas concentration in the insulation spaces; gas samples are taken successively and automatically at the gas detectors location, in order to get a complete scan of the insulation space.

All measurements are taken locally and transmitted to the DCS (Distributed Control System).

In addition, a gas alarm will be activated in the Control Room, should an unexpected gas concentration value be recorded. In the event of the gas concentration reaching 1.5% by volume in the primary space, it is necessary to sweep with nitrogen in order to reduce the gas concentration.

A good seismic behavior

The membrane tank copes more easily with seismic induced loads than the 9%Ni technology, thanks to its design philosophy.

During an earthquake, the primary container of a 9%Ni tank is submitted to lateral and vertical accelerations. Thus, the inner tank (self-standing steel shell) needs to be anchored into the slab to resist the up-lift.

Such a system consists of metallic (9%Ni) anchors cast into the concrete slab; consequently, the delivery of the 9%Ni material must take place earlier in the construction schedule. Moreover, this anchoring system causes several penetrations through the bottom of the TPS (Thermal Protection System) and increases its fragility.

On the other hand, the membrane containment system for the storage tanks is such that the pressure loads due to the liquid motions are directly transferred to the concrete outer tank through the insulation, contrary to the 9%Ni Full containment technology. Thus, there is no need for special anchoring of the containment system, as in the 9% Ni full containment technology.

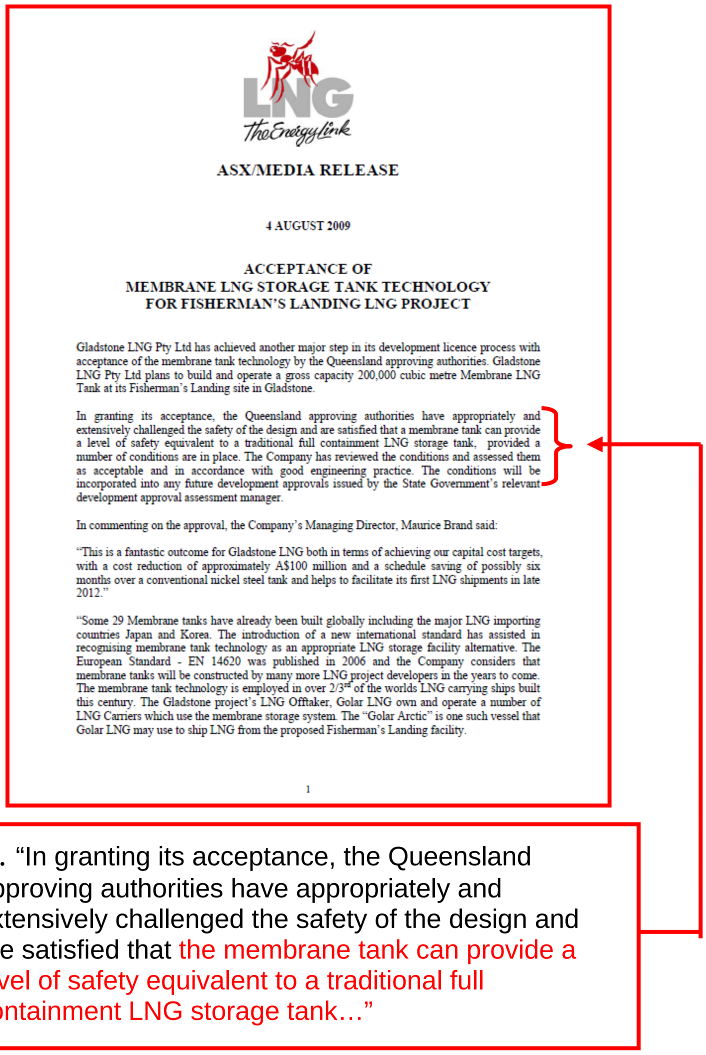
Safety

In terms of safety, the European standards EN 14620 and EN 1473 have recognized the Membrane Containment technology as safe as the 9% Ni type full containment. Both technologies are the only ones that do not require a dyke according to the chapter 7.1.11 & 7.1.12 of the EN 14620 standards.

Comparative QRA’s (Quantitative Risk Assessments) have been carried out by independent companies and the conclusion of the latest one (2009) was:

“Full containment and membrane tank types provide some of the highest integrity options for above ground refrigerated liquefied gas storages.”

Finally, the safety review performed by the Queensland Authorities concluded that the membrane technology for the LNG storage tanks could be built in that State of Australia, as announced in the following media release.



ASX/MEDIA RELEASE

4 AUGUST 2009

ACCEPTANCE OF
MEMBRANE LNG STORAGE TANK TECHNOLOGY
FOR FISHERMAN'S LANDING LNG PROJECT

Gladstone LNG Pty Ltd has achieved another major step in its development licence process with acceptance of the membrane tank technology by the Queensland approving authorities. Gladstone LNG Pty Ltd plans to build and operate a gross capacity 200,000 cubic metre Membrane LNG Tank at its Fisherman's Landing site in Gladstone.

In granting its acceptance, the Queensland approving authorities have appropriately and extensively challenged the safety of the design and are satisfied that a membrane tank can provide a level of safety equivalent to a traditional full containment LNG storage tank, provided a number of conditions are in place. The Company has reviewed the conditions and assessed them as acceptable and in accordance with good engineering practice. The conditions will be incorporated into any future development approvals issued by the State Government's relevant development approval assessment manager.

In commenting on the approval, the Company's Managing Director, Maurice Brand said:

"This is a fantastic outcome for Gladstone LNG both in terms of achieving our capital cost targets, with a cost reduction of approximately A$100 million and a schedule saving of possibly six months over a conventional nickel steel tank and helps to facilitate its first LNG shipments in late 2012."

"Some 29 Membrane tanks have already been built globally including the major LNG importing countries Japan and Korea. The introduction of a new international standard has assisted in recognising membrane tank technology as an appropriate LNG storage facility alternative. The European Standard - EN 14620 was published in 2006 and the Company considers that membrane tanks will be constructed by many more LNG project developers in the years to come. The membrane tank technology is employed in over 2/3rd of the worlds LNG carrying ships built this century. The Gladstone project's LNG Offtaker, Golar LNG own and operate a number of LNG Carriers which use the membrane storage system. The "Golar Arctic" is one such vessel that Golar LNG may use to ship LNG from the proposed Fisherman's Landing facility.

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Figure 7. Approval of Membrane technology by Queensland Authorities

ADVANTAGES OF GST MEMBRANE TECHNOLOGY

A proven technology

As an improved version of the Technigaz membrane, GST® benefits from a strong experience of land storage systems with 29 tanks already built in Europe and Asia. The Technigaz membrane was itself an adaptation of the membrane designed for LNG tankers, which successfully equips more than 20% of today's fleet.

Improved design

Since the construction of the 29 Technigaz storage tanks, GTT has improved the design of the containment system in order to comply with the new requirements European standards EN 1473 & EN 14620, which came into effect in December 2006.

The compliance with the European standards has been achieved thanks to the addition of the TPS (Thermal Protection System) on the bottom and walls of the tank, up to a 5 m height, and which function and characteristics have been previously described. Today, **GST® is the only**

membrane system featuring a physical (mechanical) TPS, in accordance with the standards requirements.

At the same time, a new pavement was patented for GST®. Adapted to a polyhedron-shaped inner side of the concrete tank, this new lay-out uses very few different elements and thus permits a higher level of standardization. The new shapes were designed in such a way that they can be easily pre-fabricated with the existing production lines.

Moreover, this second improvement leads to a simplified erection of the containment system and therefore a shorter construction schedule compared to a similar capacity 9% Ni type full containment tank. This schedule reduction is even more important if seismic issues have to be taken into account. Actually, in such circumstances, the full containment technology requires an additional anchoring of the inner tank, with anchor straps.

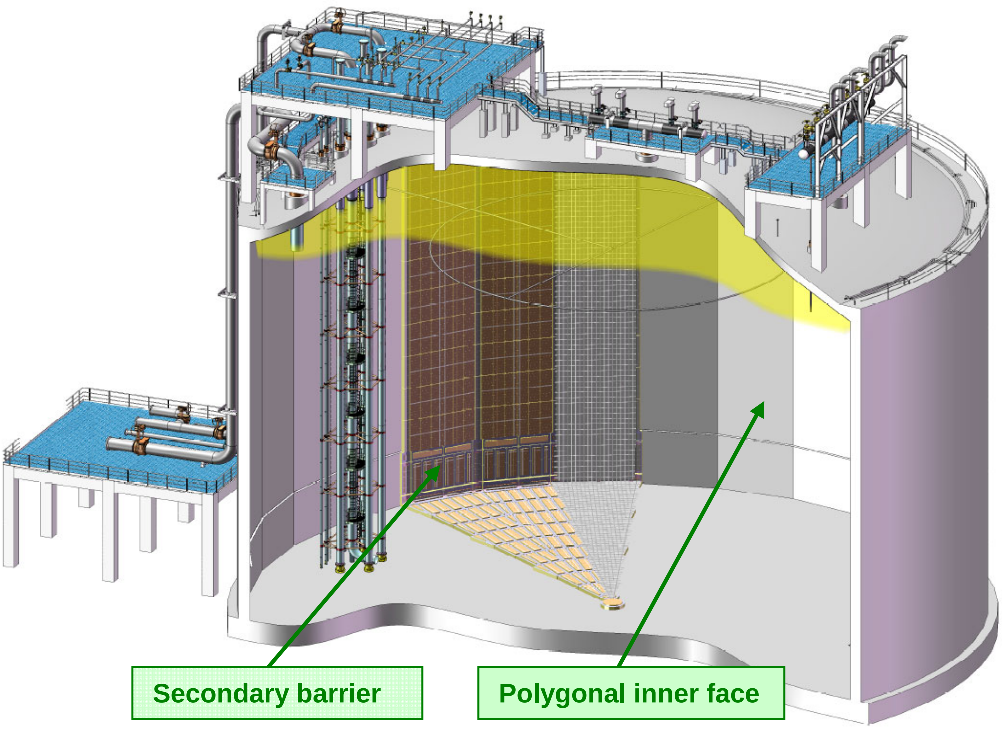


Figure 8. GST® Global View

Flexibility of GST design & suitability for very large tank capacity

As it is constituted of standard modular elements, GST® technology can be adapted to every structure, whatever its form or size, without any major changes in the design and dimensions. So far, tank construction or feasibility studies made by GTT, have covered sizes ranging from 20 000 m^3 to 300 000 m^3.

The geometrical dimensions of a GST® membrane tank depend only on the capacity and the geometry (prismatic or cylindrical) required for the storage unit.

A wide range of configurations are available, from above-ground to in-ground tanks, as well as Gravity Based Structures (GBS) and cryogenic caverns. Some examples are illustrated here below, figure 9 and figure 10.

Figure 9. Application of the membrane technology to cryogenic caverns

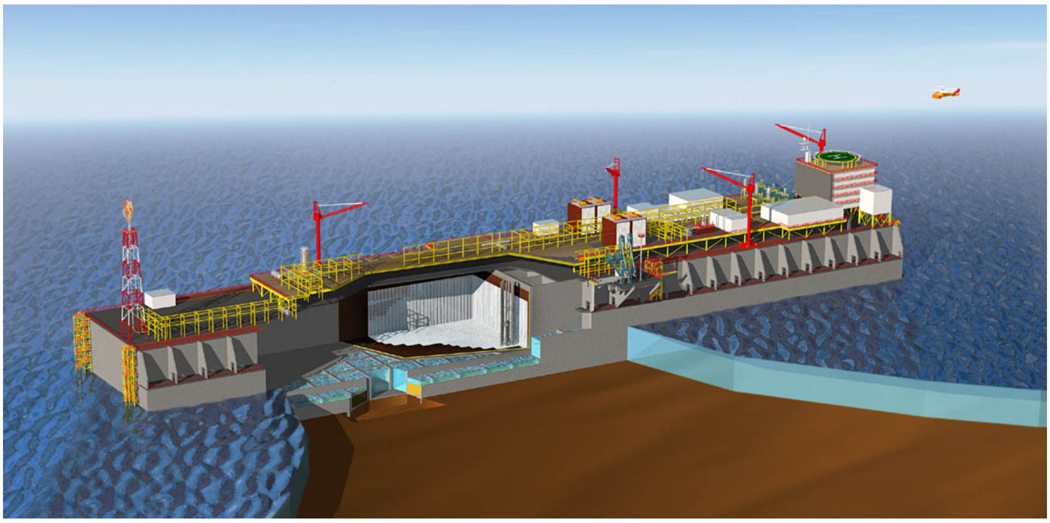


Figure 10. Application of the membrane technology to GBS

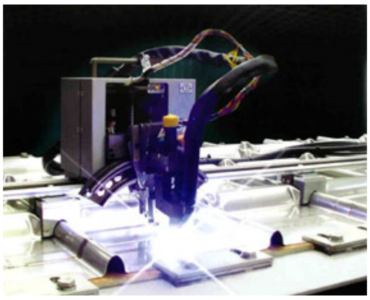
Simple erection – Light equipments

Thanks to a simplified design using 1.2 mm thick stainless steel membrane and modular elements, the erection of the containment system is optimized.

The membrane elements are positioned so that the welding process is automated. Specific welding machines have been developed to reduce erection time. They allow an automatic welding of the corrugated membrane. These welding machines are small and easy to handle, like the other erection tools, as shown on the figure 11 below.

Resin depositing machine

Automatic welding machine



Semi-automatic bonding machine

Adhesive application machine

Figure 11. Light equipment for membrane containment erection

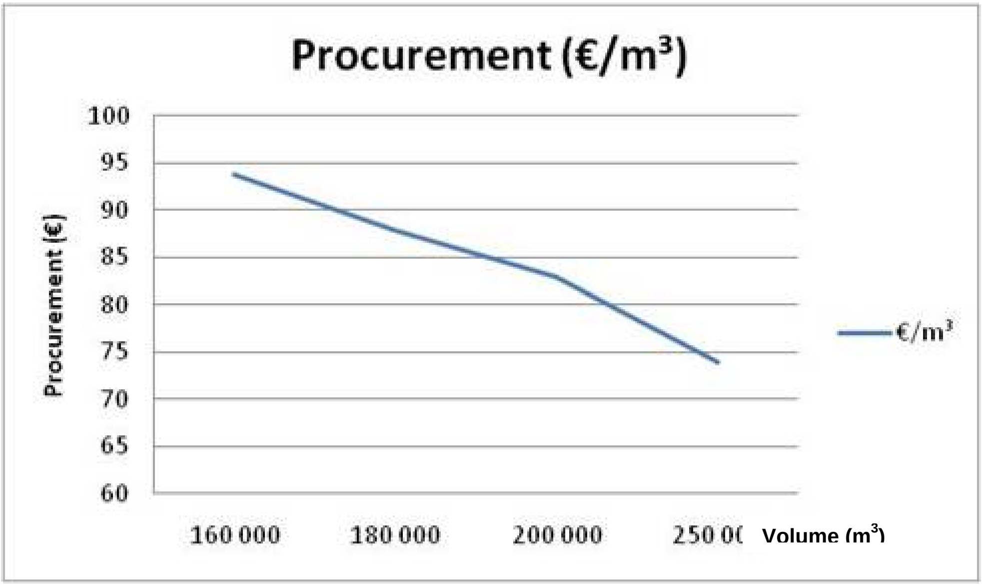
Cost effectiveness

Pre-fabricated modular elements: to improve the cost competitiveness of the technology, the GST® concept relies on the combination of a limited number of basic modular components. These pre-fabricated elements are very similar to the ones already fitted on LNG carriers. This design choice allows to benefit from existing industrial production lines and a short delay for supply. The size of these elements makes them easy to handle. Their design simplifies the construction and therefore, makes it possible to use local workforce

Procurement: Table 2, below, gives some indications on the containment price per cubic meter and for different storage volumes. These prices include all the materials used for the containment system (moisture barrier, insulation panels, membranes – primary and secondary-, fastening devices, monitoring system and corresponding tests) as well as the license fee.

These figures confirm the procurement cost effectiveness for larger storage tanks.

Table 2. Containment system cost per m^3



Labour: the labour costs of the membrane type containment system will be compared to those of the 9% Ni type full containment. Based on the fact that concrete container and tank externals are very similar for both technologies, the costs will be compared on the basis of their containment system only.

Regarding the membrane technology, the containment system erection time includes all the steps from the moisture barrier installation to the closing of the temporary opening. For the 9% Ni type full containment, the erection time includes all the steps from the liner installation to the closing of the temporary opening.

The membrane containment system erection can be divided in 5 main steps:

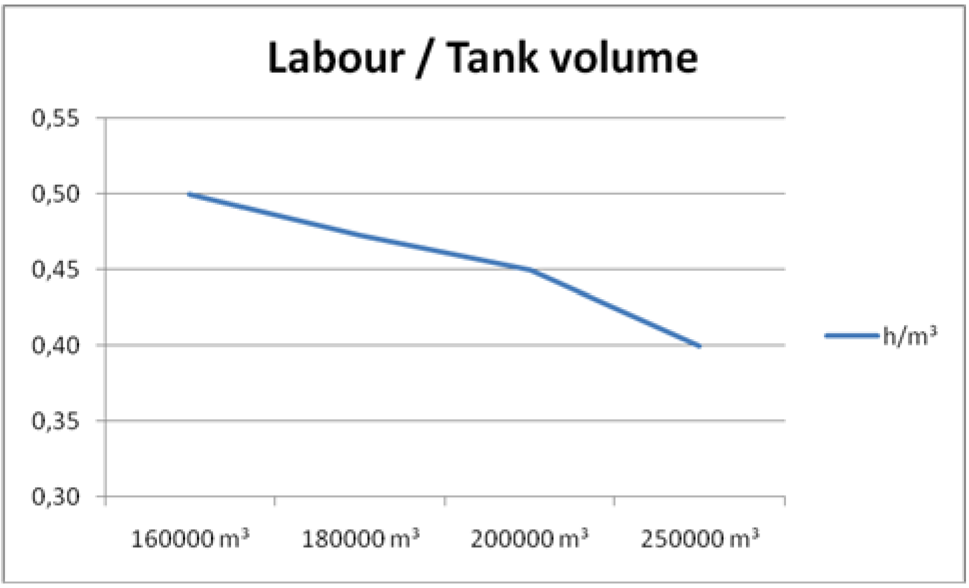
- The preparation of the tank (Moisture barrier application, marking-out, studs fitting)
- The insulation (installation of insulating panels)
- The Thermal Protection System (bonding of the secondary membrane)
- The stainless steel membrane (welding of the primary container)
- The tests (global and ammonia)

Labour requirements for the membrane containment system erection represent about 20% of those for the total tank construction.

Studies carried out have demonstrated that whatever the tank size, GST® membrane tanks required about 50% less man hours than similar capacity full containment tanks.

The following table 3 gives some time estimations for the containment erection, compared to the tank volume. Again, this gives evidence of the interest of the membrane technology for large tank capacities.

Table 3. Required labour for erection of membrane containment system vs volume of the tank



Erection schedule reduction: The tank geometry and assembly methods allow different tasks to be carried out at the same time. The general planning of the building process is thus relatively flexible. Thanks to this flexibility, **the erection schedule of the containment system can be reduced by 3 months**, compared to the 9%Ni type full containment.

CONCLUSION

The purpose of this paper was to highlight the advantages of the membrane technology used in LNG Land-based storage tanks. The demonstration was based on three types of data: historical, technical, economical. They can be summarised as follows:

Historical: a long experience offshore and on-shore, proves the **reliability** of the system

Technical: a double containment system and a TPS (Thermal Protection System), guarantee the **high safety level** of the GST® membrane containment system.

Economical: the simplified modular technology, the industrial pre-fabrication of the containment elements, the easiness of the erection make the GST® membrane system very much **cost and schedule effective.**

We are convinced that GST® brings a novel answer to the market needs and that it has well taken into consideration the demand's parameters and it addresses them in an optimised way for the benefit of the community at large.

ACKNOWLEDGMENTS

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The author would like to extend her acknowledgments to the people who have contributed to this paper by sharing their experience and knowledge, and in particular the technical staff of GTT, involved with the development of the GST® membrane containment system.