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Tango FLNG - From Contract to Production in Less than 6 Months

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Abstract

Argentina is evolving from a natural gas importer to an exporter, thanks to the development of the Vaca Muerta formation in the Neuquén Basin. The Argentinean National Oil Company is still ramping up production, but already there is excess gas available for export in the form of LNG to international markets. The Caribbean Floating LNG (CFLNG) barge had been completed for another project, which unfortunately had been cancelled due to bankruptcy of the Client. In August 2018, the two companies met ‘over a cup of coffee’ to see if CFLNG could be deployed as a pilot production system for LNG export in Bahía Blanca, Argentina.

CFLNG was designed as a small-scale liquefaction system of 0.5 MTPA capacity, using pipeline quality feed gas. The paper will describe the design considerations made at the time, as well as the Engineering, Procurement, Construction and Commissioning activities to complete the unit for its alternate feed gas and location. Especially the latter was a major undertaking, since validating CFLNG’s liquefaction performance comprised loading 270 road trailers LNG into its cargo tanks, installation of a temporary LNG vaporization skid, to be able to complete the contractual full 72-hour liquefaction performance test, all while docked quayside at the construction yard.

Also, the paper will address the modifications made to the unit to moor it alongside an existing jetty in Bahía Blanca, to receive gas from shore, as well as the provisions made onshore for pre-treatment and pressure boosting of the feed gas.

After the initial contact with the end customer, due diligence inspections and engineering studies were performed on how CFLNG could be deployed in Argentina. Soon, both parties realized the unit was a good match. A contract was signed on November 20th, 2018: Caribbean FLNG was now to become Tango FLNG.

Site specific modification and reactivation works were carried out in China, where the unit was laid up. It was loaded onto a semi-submersible heavy lift vessel (HLV) close to Shanghai, late December 2018. In parallel, gas treatment and compression equipment was sourced and procured, and modifications to the jetty were completed. The unit arrived in Bahía Blanca in February 2019. After mooring up, commissioning activities were started, ultimately resulting in the successful delivery of a first LNG cargo on June 6th, 2019. Noteworthy detail is that Tango FLNG is moored to the same Jetty that was used to import LNG to Argentina for 10 years!

The project demonstrates that the FLNG concept is flexible and can be redeployed to other locations. The Start-up of Tango FLNG is the start of LNG export for Argentina.

Introduction

The floating liquefied natural gas (FLNG) unit, shown in Figure 1, is a liquefaction unit that produces approximately 0.5 million metric ton per annum (MTPA) of liquefied natural gas (LNG). The unit is a fully self-sufficient barge, designed to be moored near shore. The 12 megawatts (MW) power plant uses dual fuel generator engines.

Figure 1—Tango FLNG

The FLNG contains three IMO Type C cargo tanks with a total LNG storage capacity of 16,100 m^3.

The topsides facilities include gas treating (amine and dehydration units), liquefaction, refrigerant make-up, boil-off gas (BOG) handling, BOG reliquefaction, a hot oil system, and other supporting utilities. Liquefaction capability is provided by single mixed refrigerant (SMR) technology. Pipeline gas is treated and liquefied on the topsides before being sent to the cargo tanks. From there, the LNG is periodically offloaded to a floating storage unit (FSU), or, directly onto an LNG carrier for transport to end users.

The idea for developing FLNGs was conceived in 2008. FID took place in mid-2012. The FLNG project was originally intended to be delivered under a long-term charter agreement to a Canadian company. The unit was to be installed offshore Tolú, Colombia. However, with the significant turmoil in the oil and gas market in 2015, the end client filed for bankruptcy and the Colombian LNG export project was cancelled.

With the construction nearing completion and the destination unknown, the entire project plan needed to be revisited. It was decided to further complete the FLNG in absence of a final destination and priority was given to develop a solution for the FLNG to be fully commissioned at the construction yard. This led to the development of the closed loop commissioning concept using a temporary regasification skid (TRS). Regasification equipment was readily available from a Floating Storage and Regasification Unit (FSRU) project being constructed at the same yard, and using that equipment, a TRS was designed and constructed to be temporarily installed onboard the FLNG.

This alternative commissioning has provided an elegant way to close out the performance test requirements under the EPCIC contract while the end destination of the FLNG remained unknown. This successful operation did further provide unique assurance for future potential customers that the unit had met full performance as per the intended design.

Once the performance test of the FLNG was completed at the construction yard in China in 2016, the unit was put in lay-up mode, awaiting a new project to be negotiated. Eventually a contract was signed for the unit to operate in Argentina.

Commissioning of the FLNG at the construction yard

In order to prove that the FLNG was capable to perform as per the intended design, a full gas commissioning of the unit took place at the construction yard in China. The natural gas was put in a closed loop mode where it was both vaporized (utilizing the TRS) and liquefied in a continuous mode on board.

The TRS takes LNG from its cargo tanks and vaporizes it, providing HP feed gas to the liquefaction facilities. The vaporized natural gas stream connects with the topsides process units at the inlet feed gas manifold. Gas flows through the normal sequence of the topsides units – amine treating, dehydration, and liquefaction. The LNG produced is sent back to the cargo tanks.

Figure 2 shows a high-level overview of the process flow scheme.

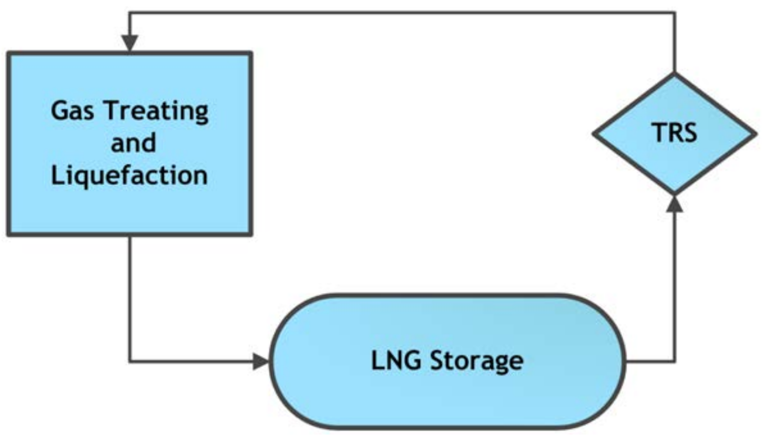

Figure 2—Block process flow diagram

The alternative commissioning arrangement of the FLNG was nearly identical to the original design; the main exception was that the feed gas was delivered by the TRS as vaporized LNG instead of as feed gas from a pipeline. The topsides operation was essentially identical to normal operation.

The gas was fed to the front of the plant through an inlet separator to the amine unit where carbon dioxide (CO_2) can be removed. Since the gas sourced during commissioning was vaporized LNG, the CO_2 in the gas stream was already below the required levels for liquefaction. The treating unit operated with diluted amine solution to prove that the mechanics of the unit are acceptable. The water saturated gas from the amine unit then entered the dehydration unit, where molecular sieve material removed the water before the gas was sent to the liquefaction unit. The dehydration unit was tested in full operational conditions. Recycled BOG was used to regenerate the saturated sieve bed. The wet regeneration gas was then used for fuel in the gas turbine that drives the liquefaction refrigerant compressor.

In the liquefaction unit, the gas was partially cooled and sent to the heavies separator. The separated liquid heavies stream was vaporized and used as fuel, while the remaining vapor was cooled further and condensed to produce LNG. The SMR refrigerant cycle, driven by an LM2500+ gas turbine, provided the necessary chilling duty to condense the required amount of feed gas to LNG.

The LNG produced was then sent to the cargo tanks. The flash gas and BOG were compressed and used as fuel for power generation and the gas turbine. Any excess BOG was reliquefied in the main refrigerant exchanger. The LNG was pumped to the TRS by the cryogenic deep well pumps in the cargo tanks. A high-pressure pump increased the LNG pressure to match the feed gas design conditions. High-pressure LNG was then vaporized using an intermediate fresh water loop. The vaporized LNG was sent as feed gas back to the front of the plant.

A small amount of gas was constantly consumed by the power generators and the liquefaction gas turbine, but the majority of the LNG/gas continued to recycle in this processing loop throughout the commissioning activities.

For the entire commissioning and performance testing of the FLNG, a total of approximately 12,000 m^3 of LNG was used. The vast majority of the LNG was consumed as fuel for the dual fuel engines and gas turbine, and for cooling down the cold box. The LNG was brought on board in parcels of not more than 3,000 m^3 with LNG trucks. In this way the logistics could be managed properly. As an additional advantage, using this system limited the LNG inventory on board to a safe minimum level considering the close proximity to the heavy industry nearby.

Drawing on the extensive experience in LNG transshipment, LNG hoses were chosen as the transfer means (Figure 3).

Figure 3—LNG delivery trucks

Small hoses were connected between the trucks and the LNG loading skid. These hoses were fitted with a quick connect/disconnect coupling to ensure smooth operations when connecting to the truck. A breakaway coupling was inserted to ensure no LNG liquid spill would occur if the truck had to leave in an emergency.

One large LNG hose was fitted between the LNG loading skid and the FLNG manifold. This hose was fitted in a way that it would compensate for the FLNG movements alongside the berth. A breakaway coupling was installed as well to ensure no LNG spill would occur should the FLNG depart from the berth unexpectedly.

LNG was loaded onto the truck at an existing LNG facility which is about 150 km driving distance from the construction yard. At this terminal, the LNG quality was checked by analyzing samples. The LNG quantity loaded on the trucks was confirmed by weighing each truck. In total, for the entire commissioning and performance testing of the FLNG, 270 trucks were discharged at the construction yard. The entire operation of connecting, discharging, and disconnecting two trucks, including paperwork, took approximately 4.5 hours, on average. Each truck delivered approximately 20 MT of LNG.

Argentinean LNG Export Project

Project description

For many years, Argentina has been importing LNG to cover the energy and heating needs, especially during the winter seasons. Up to 2018, Argentina was using two LNG import terminals in the Buenos Aires province: one at Escobar in the North and one at Bahía Blanca in the south. In the recent years large shale gas discoveries have been made in the country, mostly concentrated in the Vaca Muerta Formation at the Neuquén Basin. The natural gas production from these resources is being increased, and is able to cover for more than the domestic needs, especially in the southern part of the country. In 2018 it was predicted that surplus natural gas would become available. The natural gas producer recognized this and found with the CFLNG unit a unique opportunity to monetize the excess in natural gas with an extremely fast relocation and start-up time.

While the FLNG was being held in lay-up at a Chinese yard berth, first talks happened between the interested companies in August 2018. The feed gas characteristics, location and local environment were evaluated.

Feasibility studies were executed together with the Client in a quick way to ensure the FLNG unit could operate in the Argentinean waters. In parallel, contract negotiations took place. All of this was completed in less than 3 months' time, leading to a formal contract signing on November 20th, 2018. At this moment, the unit was also formally re-named to Tango FLNG.

As the unit needed to be adapted to the local site conditions, design, engineering, and construction works were completed almost in parallel to ensure the sail-away could occur as quickly as possible. This successful upgrade of the unit was completed on December 21st, 2018. The unit was loaded on a HLV on December 28th, 2018, starting the voyage to its operational destination at Bahía Blanca, Argentina.

Figure 4—Tango FLNG loaded on the HLV

Tango FLNG is now permanently moored at the terminal in the port of Bahía Blanca. For the past 10 years that jetty was used to import LNG to Argentina using FSRUs. This location was selected as all facilities to handle high pressure natural gas were already in place. These include an existing jetty, a high pressure loading arm, and a pipe line grid which was ready for operations. Only the flow direction needed to be reversed.

On February 2nd, 2019 the heavy lift vessel arrived in Bahía Blanca. The sea fastening was removed and two days after the arrival, the TFLNG was offloaded from the HLV and safely moored on site. This marked the start of the commissioning operation whereby in the first weeks of commissioning all utility systems were started, leading to the introduction of the first feed gas on April 2nd, 2019.

Once the testing of all systems under gas was successfully completed, the unit was started up and immediately began producing LNG. After an initial tuning of the process topsides (which took about 5 days) was completed, a new performance test was started. During the 72-hour continuous run time, it was proven that Tango FLNG was producing LNG well above its guaranteed capacity. The performance test was successful. The unit went into commercial operations on June 6th, 2019.

Tango FLNG is producing approximately 500,000 MT of LNG a year. To export this quantity of LNG, up to eight LNG carriers will be loaded each year. Thanks to the Tango FLNG, Argentina is transformed from a natural gas importer to a reliable LNG supplier in an exceptionally short time.

New process requirements

Tango FLNG was designed for one specific location and gas field in Colombia. Before Tango FLNG was deployed in Argentina, the pre-treatment and liquefaction processes were reassessed to:

- Evaluate if it could operate with the supplied natural gas from the Argentinean gas grid and
- Check the impact on the production capacities.

Table 1 below gives a comparison between the original design basis for the feed gas and the new design basis using the Argentinean feed gas.

Table 1—Comparison of Feed Gas Compositions

Component		Unit	Argentinean feed gas	Original design
Feed Gas Pressure		[Barg]	54 – 76	76
Feed gas temperature		[°C]	7 – 40	7 – 40
Carbon dioxide	CO_2	[mol %]	0.200	0.070
Nitrogen	N_2	[mol %]	1.054	2.100
Methane	CH_4	[mol %]	94.454	97.230
Ethane	C_2H_6	[mol %]	3.443	0.400
Propane	C_3H_8	[mol %]	0.436	0.090
I-butane	$i\text{-}C_4H_{10}$	[mol %]	0.095	0.010
N-butane	$n\text{-}C_4H_{10}$	[mol %]	0.091	0.010
I-pentane	$i\text{-}C_5H_{12}$	[mol %]	0.022	0.010
N-pentane	$n\text{-}C_5H_{12}$	[mol %]	0.015	0.030
Hexane	C_6H_{14}	[mol %]	0.010	0.020
Heptane	C_7H_{16}	[mol %]	0.005	0.020
Octane	C_8H_{18}	[mol %]	0.001	0.010
Nonane and above	C_9+	[mol %]	0	0
Water	H_2O	[mg/m³]	< 97	< 97
Hydrogen sulfide	H_2S	[ppmv]	< 0,5	-
Oxygen	O_2	[ppmv]	< 20	< 20
Mercury	Hg	[µg/nm³]	< 0,2	< 0,2
BTEX	-	[ppmv]	< 15	< 15
TEG	-	[ppmv]	<100	-

As can be seen, the Argentinean feed gas is significantly heavier compared to the original lean design feed gas. There is a much higher ethane and propane composition, and an equally lower amount of methane. By using the SMR technology and by the specific design of the Tango FLNG topsides process, this large difference in feed gas composition was demonstrated to not have any significant impact on the overall performance of the unit.

The following three main challenges where discovered during this analysis to deploy the Tango FLNG within the very short start-up schedule:

Higher CO_2 concentration in the feed gas.. Multiple gas samples showed that the CO_2 concentration in the Argentine feed gas is approximately 2~2.5 mol % which is much higher than the Tango FLNG amine treatment plant design basis of 0.2 mol % CO_2 concentration. In the preparation to re-deploy the liquefaction barge, a design was readily available to upgrade the on-board pre-treatment amine plant to make it able to remove CO_2 up to 2.0 mol % concentration. However, the challenging project schedule didn't allow this modification on board because of the long lead time for certain new equipment.

To ensure this high CO_2 concentration was not going to become a show-stopper, efforts were undertaken to search the natural gas equipment market for the availability of mobile, ready-to-deploy amine treating plants. It turned out that this was indeed the case. There are a few suppliers which keep a stock of equipment for standard 100 gpm circulation rate amine units. These mobile CO_2-removal units have a standard feed gas throughput capacity of about 1 million Sm^3/day while handling feed gas with a CO_2 concentration of maximum 2.0 mol %. Since the feed gas needs for Tango FLNG are up to 2.4 million Sm^3/day, the end customer decided to procure two of such mobile amine units for installation onshore at the jetty.

Both amine plants came from different locations. They arrived at the Jetty in Bahía Blanca in January 2019. They were installed, tested, and commissioned in parallel with the installation and commissioning of Tango FLNG.

Both amine plants need to run in parallel. To reach the required feed gas throughput capacity, a bypass line was also installed. The amine plant which was already installed on Tango FLNG is used in series with the shore plants to ensure that all the CO_2 of the entire feed gas stream can be reduced to below 50 ppmv which is needed for the liquefaction plant.

High Heavy hydrocarbons concentrations.. The gas grid in Bahía Blanca is supplying several large petrochemical plants in the proximity of Tango FLNG. The delivered feed gas composition to Tango FLNG is highly affected by the activities of these plants. The liquefaction technology which is used on the Tango FLNG has the advantage that it can be used for a wide range of gas compositions. Hence the higher concentration of heavies, up to a certain limit, is not an issue to process the supplied feed gas.

The complexity of the fluctuating heavies concentration is that the process parameters of the heavies removal system need to be adjusted continuously to ensure the right amount of heavies are knocked out from the feed gas stream, on the one hand to avoid the cold box being clogged by freezing of the heavier components and on the other hand to avoid that too much NGLs are sent to the heavies removal system.

Low feed gas pressure. The Argentinean natural gas grid where Tango FLNG is receiving its feed gas has an operating pressure of about 55 barg. Tango FLNG was designed however to operate with a feed gas pressure of 76 barg. After multiple process simulations, it was proven that the natural gas still can be liquefied at the lower feed gas pressure albeit with a slightly reduced production capacity. To maximize the production, it was decided that a booster compressor needed to be installed to increase the feed gas pressure to a minimum of 70 barg.

To meet the projected schedule, the Tango FLNG started its production on the lower feed gas pressure and proved that it was able to produce LNG. During the Argentinean winter in 2019, when production was stopped for a while due to a lack of feed gas, an onshore booster compressor was installed and tested. With this booster compressor, Tango FLNG receives its feed gas close to the design pressure so it can produce LNG at its full rate.

Revised mooring arrangement

At the original terminal in the Gulf of Morrosquillo, Colombia, the FLNG barge was to be moored in an array of eight Ø 2.10 m mono piles which allowed it to freely float up and down while its horizontal motions were restrained. An LNG Carrier serving as FSU would be moored on Starboard at 7.0 m distance to an independent jetty, comprising of eight Ø 2.40 m mono piles, four serving as breasting dolphins and four as mooring dolphins.

On Port side, a small riser platform was to be placed, from which the feed gas would be transferred to the FLNG's manifold via a flexible pipe.

For export, an LNG Carrier would come alongside the FSU to load a full cargo parcel.

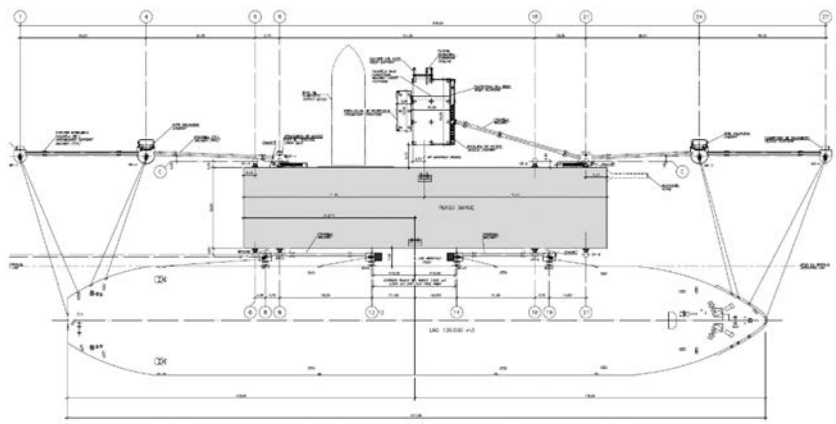

Figure 5—Original FLNG terminal arrangement

For the Argentinean layout, the FLNG barge had to be moored to an existing jetty which was originally used for export of LPG. It was converted to an LNG import terminal in 2008 for the Bahía Blanca Gas Port FSRU project and thus could be rapidly converted to accommodate the FLNG barge.

The originally foreseen mono pile mooring arrangement could not be implemented. Also, the visiting LNG carrier had to be moored directly alongside the FLNG barge, with its spring lines secured on the FLNG barge. Thus a new mooring arrangement, compatible with the new jetty, was to be developed and side-by-side mooring equipment was to be fitted to accommodate visiting LNG Carriers.

The main challenges for the FLNG barge's new mooring were time and space. Not only was a complete new mooring system to be conceived, it also had to be reviewed and approved by the Argentinian (Port and Maritime) Authorities. In addition, it was opted to have the barge's mooring classed to BV rules (POSA-JETTY notation). All new equipment for the FLNG barge and the jetty had to be specified, sourced, procured, and installed before the unit left the Shipyard (in less than 4 months) or, in case of the jetty, before the unit arrived on site (in less than 6 months).

Both parties agreed to use one Spanish consultant for the mooring analyses, to ensure timely completion of the work such that all regulatory approval from the Argentinian Authorities before start of LNG production.

A mooring arrangement was developed, in which the FLNG's HP gas manifold lined up with the HP gas loading arm on the jetty. A total of 14 mooring lines plus two 2 storm lines were deployed to the existing quick release hooks (QRHs) on the jetty. The storm lines are deployed only in case of predicted severe weather from the North East to North West quadrant when no LNG Carrier is present.

For an overview of the mooring analyses work, one can refer to the paper presented at Gastech 2019 by [Luiz Lopez et al, 2019].

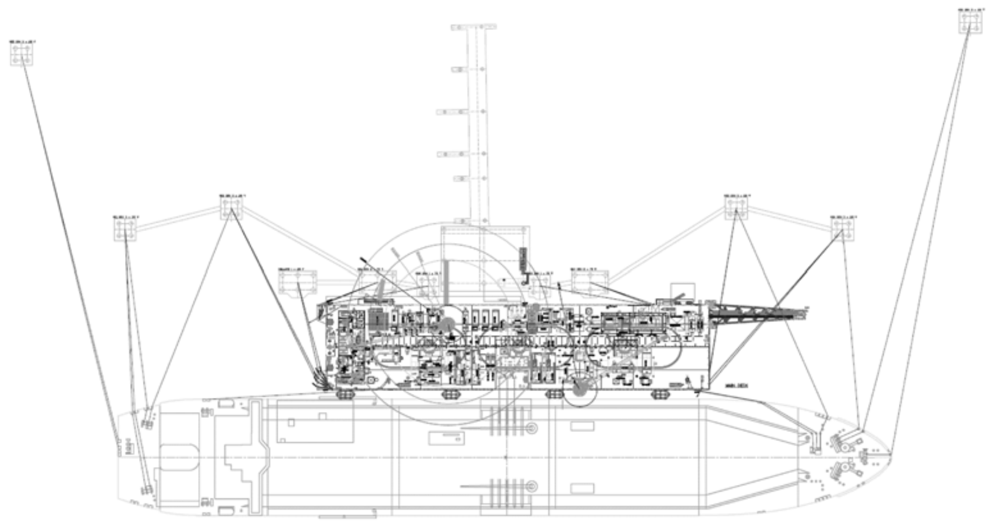

Figure 6—Revised Tango FLNG terminal arrangement

As time was too short to procure ‘long lead’ equipment (i.e. mooring winches) it was decided to develop a mooring with fixed length lines with sufficient elasticity to accommodate the geometric length variations due to tide and barge draft changes. This choice resulted in a complex and time consuming mooring analyses as a balance was to be found between mean line tensions at high tide and dynamic (peak) line tensions at low tide, with the only parameters to play with being the relative stiffness of the mooring lines and, to a lesser extent, the initial length of the mooring lines. The problem was exacerbated because the minimum breaking load (MBL) for the mooring lines was fixed at 124 MT before the mooring analyses were completed; this so that procurement and engineering could start on time to match the conversion schedule in the shipyard.

To allow easy handling, HMPE ropes were selected, with elasticity being provided by PA tails. To have some adjustability in length, a chain pendant was fitted on the inboard end which was secured in a standard marine JIS type chain stopper.

Synthetic ropes experience significant permanent elongation from ‘bedding in’ under load. For HMPE, this is about 2.5% (see Figure 7) but for PA tails this reaches 8%. In consultation with the rope manufacturer it was decided to pre-load the ropes after splicing to 50% MBL to take out this construction stretch. While this was effective for the HMPE ropes, this was only partly successful for the PA tails, as these showed a 5% recovery in length, several days after unloading.

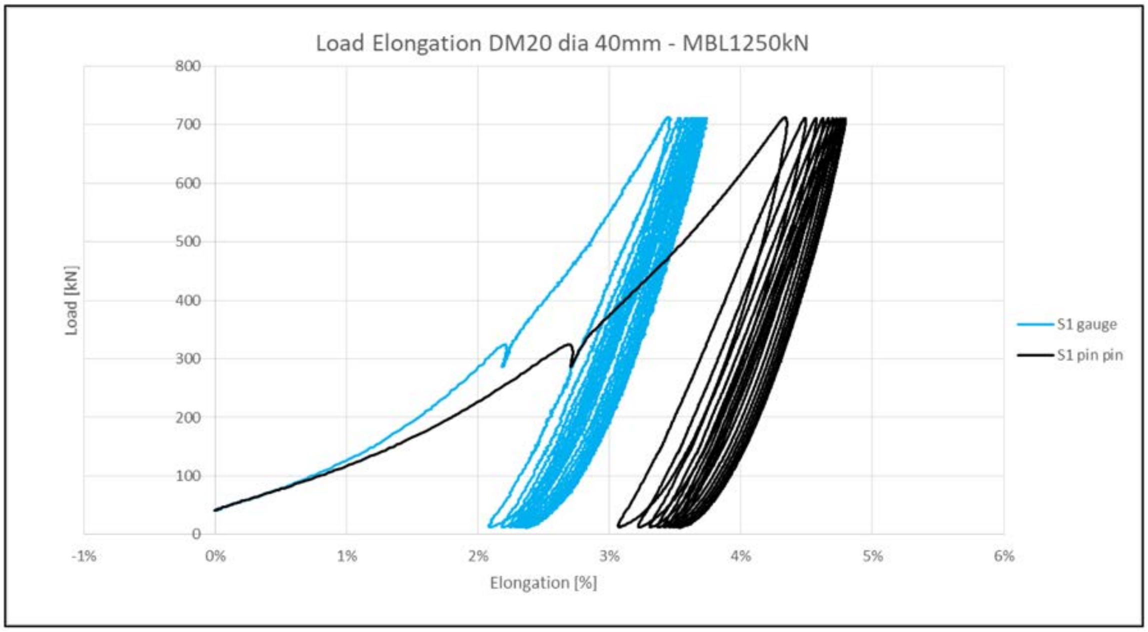

Figure 7—Cyclic load testing HMPE Rope

As part of the BV certification, an extensive rope qualification program per [MEG4 – Appendix B] recommendations was performed. Break-load tests (straight line and angled), immediate strain test, endurance, and axial compression fatigue tests were performed for the HMPE ropes, as well as yarn strength tests at various temperatures. For the PA tails, break-load tests in wet condition, tension fatigue tests, immediate strain test and dynamic stiffness tests were completed. In all, the program lasted four months and was only completed after the mooring was installed on site, but before LNG commissioning started.

Rope lengths were corrected for anticipated construction stretch. In addition, a 3-D survey of the jetty was performed before the ropes were spliced; this to ensure that the HMPE and PA ropes were spliced to the correct lengths.

Hook-up of the mooring ropes to the jetty was a challenge because only limited pull-in capacity was available on board Tango FLNG. Under guidance of the rope manufacturer, a procedure was devised, in which a mooring line was first secured in its chain stopper on the FLNG barge and then tensioned up on the mooring dolphin end with the QRH's capstan winch at low tide. In the first pass, the PA tail would be too short to fit over the hook prong (see Figure 8). It was then tied-off to the hook with a grommet which remained in place for a full tidal cycle after which the tail had stretched enough to be pulled over the hook prong at the successive low tide.

Figure 8—Hook-up of PA tail to QRH

The upper deck of the FLNG barge is full of equipment. No space was available to fit the new mooring gear. This constraint was overcome by building two new platforms on the barge's stern at main deck level, on which the chocks and chain stoppers were fitted in which the aft head-, breast- and spring lines were secured.

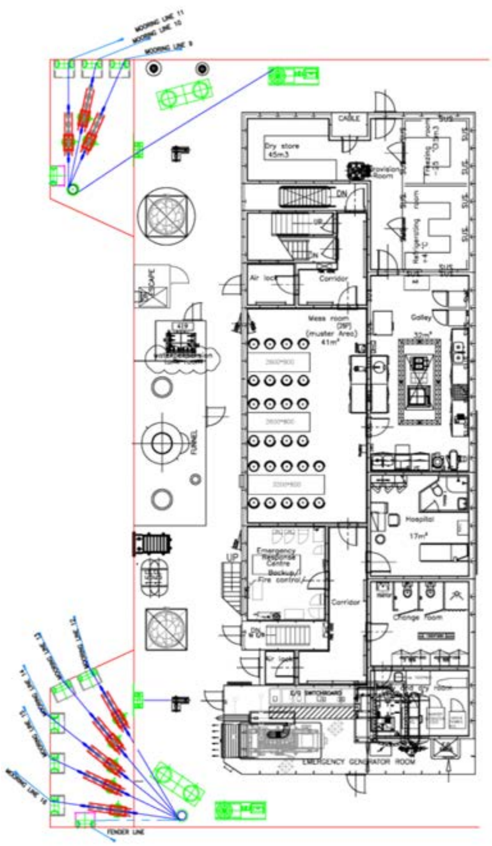

Figure 9—Aft mooring platforms

The forward mooring lines were terminated below main deck on 2[nd] deck. Downside of this location was that the 2[nd] deck is a gas free un-classified area, used as escape way. Mooring chocks penetrating the side shell thus impaired the gas-tight rating of this space. This was remediated by 'boxing in' the mooring equipment with manhole covers closing them off once the mooring cables were secured, see pictures below.

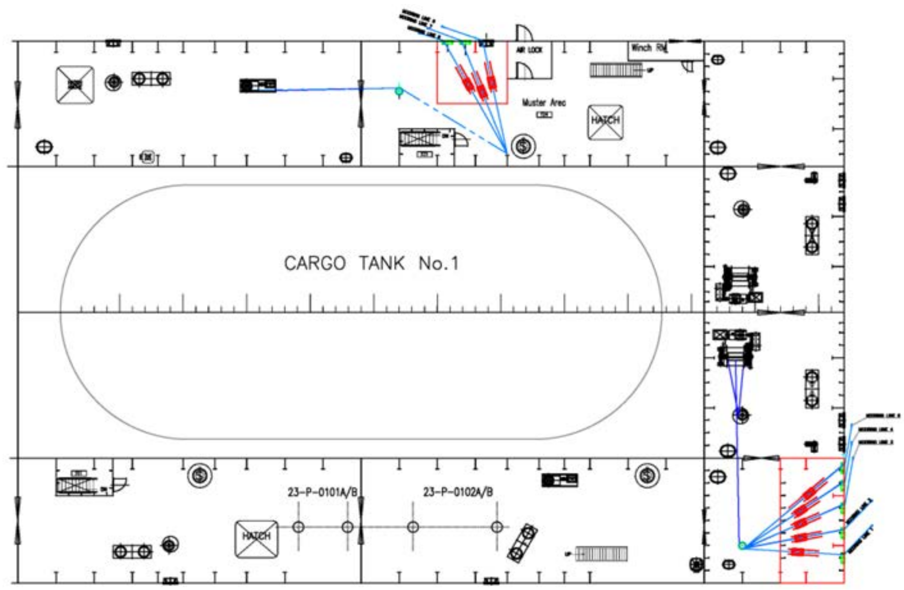

Figure 10—Forward mooring arrangement

Selection of the mooring chocks and chain stoppers and their integration into the barge's structure is dependent on the MBL of the mooring lines only and not the acting loads in the lines. Thus, the MBL for the lines was fixed early in the project, to allow sourcing of the equipment and, to start the design and engineering of the mooring integration.

Design and construction were performed in line with BV's NR 493 rules and regulations for a POSA "JETTY" notation.

Modifying Tango FLNG & preparing for operation

Before moving to the operational site, Tango FLNG needed to be taken out of the lay-up status and the necessary modifications needed to be completed to ensure the unit was fit for the Bahía Blanca terminal. Those works started in parallel with the contract negotiations and needed to be completed at latest one month after contract signing to keep the tight schedule. During the months November and December 2018, the following works were executed while Tango FLNG was berthed at the repair and conversion yard in Shanghai, China:

- De-preservation of all the equipment and systems
- Modifications of the mooring arrangement
- Modifications of the HP manifold
- Implementation of lessons learned from the initial commissioning.
- Preparation for the dry tow

De-preservation works

The unit had been in a long lay-up period of about two years. During that period, all equipment and systems had been put under a long-term preservation to ensure they would not degrade over time. A very short period was then required to put all systems back into service.

Item by item the machinery was cleaned, overhauled, and put back into service, starting with the utilities first such as the power generation system and cooling water system.

Modifications of the mooring arrangement

This was by far the most challenging work during the entire preparation period of Tango FLNG. In total 16 chain stoppers needed to be installed on board in line with 16 additional mooring chocks. To accommodate the mooring lines of the LNG carrier, 2 self-releasing mooring hooks needed to be added as well. The entire mooring modifications were split up into four work flows:

Removal of the existing mooring system. Tango FLNG was designed to be moored on eight spud piles. The brackets to connect the hull to such spud piles were already partially installed and needed to be removed from the hull as they would otherwise clash with the jetty fenders. On the portside hull, aft fenders were attached to the hull as per the original design to allow for supply boats to come alongside and moor against the hull to bring on the required supplies, fills, and parts. These structures would as well get in conflict with the Terminal jetty fenders and had to be removed.

Lastly, as the FLNG will be moored for at least 10 years at a jetty without the possibility to repaint the hull, a special glass flake epoxy coating was added in way of the fender areas to ensure the friction between the fenders and the hull would not cause excessive paint damage and corrosion.

For these modifications, which were partially below the water line, the FLNG needed to be put in a drydock. The conversion yard had several floating docks available and Tango FLNG was put in their largest floating dock. All dry-dock jobs were completed within 7 days.

The aft mooring modifications. Given the congestion on the aft main deck it was impossible to fit all additional mooring equipment inside the boundaries of the FLNG. A solution was found by adding two mooring platforms on the FLNG stern at main deck level. The aft starboard mooring platform accommodated the chocks and chain stoppers for four mooring lines and one storm line. The aft portside mooring platform accommodated the three chain stoppers and chocks for the three mooring lines and a fairlead roller to install these lines. Because of the fixed line mooring system, with mooring lines lengths which had been calculated precisely, the chain stoppers and mooring chocks had to be installed with a high accuracy on the dimensions and layout. The calculated distance from the chocks to the chain stopper needed to be respected. Equally, the orientation of the chain stopper was also very critical to keep the load in the mooring lines at acceptable levels.

The entire construction and installation of these mooring platforms was completed in a record time as indicated in Figure 11.

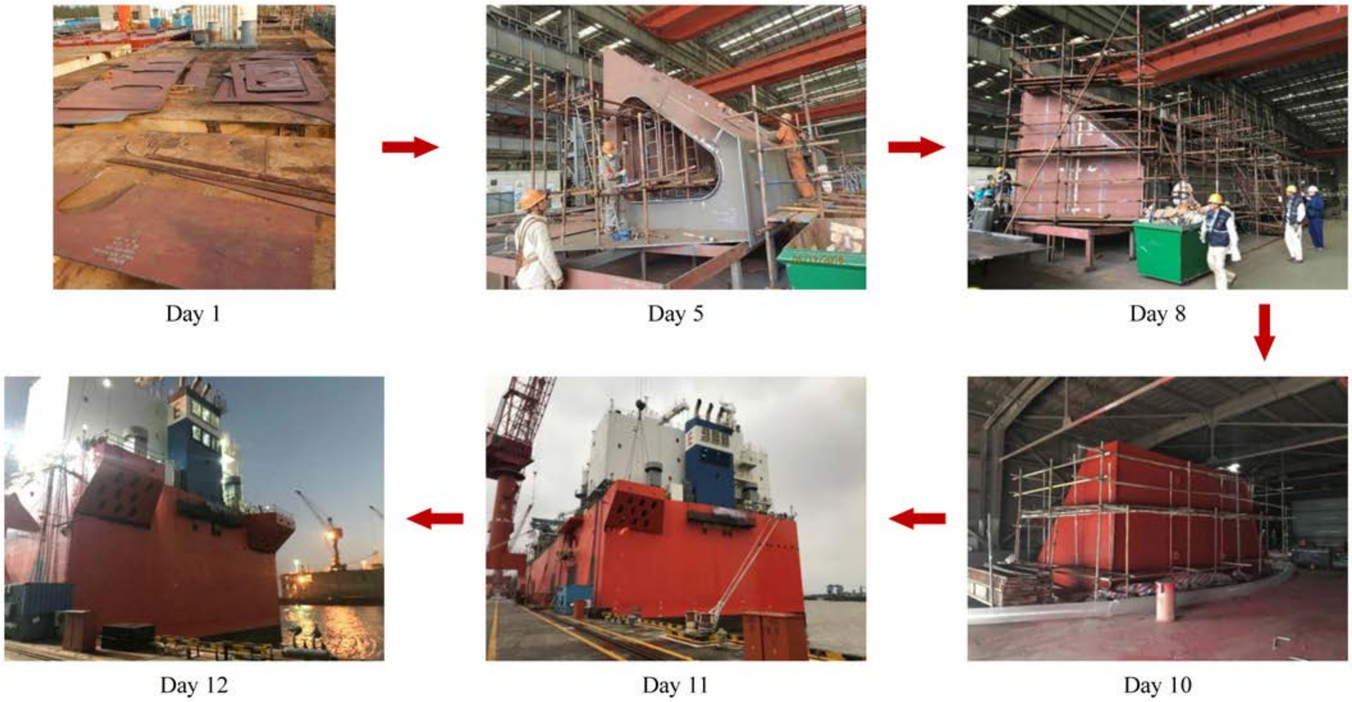

Figure 11—Construction of mooring platforms aft

The portside and forward mooring modification. While on the aft of the FLNG there was no space available, the situation was different on the other parts of the FLNG. Below the process deck, Tango FLNG has a large escape way on its 2nd deck. In that area there was still room available where the additional chain stoppers and mooring chocks could be added.

The major challenge here was the area classification. By design, the 2nd deck escape way was classified as safe zone. However, if mooring chocks were to be added with large openings to the side, the area classification would change into a hazardous zone. This would have had large implications on all the electrical systems which are installed in this escape way and it would cause a long and difficult conversion work. To overcome this, the additional mooring equipment was put in dedicated gas-tight compartments with an access through a manhole. It created some difficulties for the installation of the equipment and later the mooring lines, but it had the large advantage that the area classification of the 2nd deck escape way could be kept as a safe zone. Following mooring equipment was installed:

- Three chain stoppers with chocks forward portside
- Five chain stoppers with chocks on the forward bulkhead

Figure 12—Chain stoppers forward

Installation of quick release mooring hooks. For the ship-to-ship transfer, the LNG carrier (LNGC) receiving the LNG produced on-board Tango FLNG would be berthed alongside. In the foreseen mooring arrangement, the LNGC spring lines would be connected to the Tango FLNG quick release hooks starboard aft and forward. Space was available on the process deck to include these mooring hooks without jeopardizing the safe escape from the process deck. The major issue with this part of the mooring upgrade was that the quick release hooks could not be delivered on time at the yard. The foundation of these hooks and hydraulic lines and connections were fabricated and installed on board at the conversion yard. The mooring hooks themselves were sent from the manufacturer's shop, straight to Bahía Blanca, Argentina. The top flange of the foundation was constructed without the bolting holes. These were to have been drilled on site to give the quick release hook the exact direction required to fit with the lines chocks.

While the entire mooring modification as such might not seem as a complex work, the time on which this has been executed made it an extraordinary effort. The design, engineering, construction, installation and testing has been completed in about 45 days, starting from a blank sheet.

Modifications of the HP platform

In the original design, the feed gas would be sent to Tango FLNG through two 10" flexible high pressure (HP) gas hoses. Such hoses, which would be installed between a riser platform and the FLNG manifold, were selected and designed to cope with the movements of the FLNG. In the Bahía Blanca layout, there was no room to install this kind of hose. Instead, a high pressure articulated gas arm is installed on the Bahía Blanca jetty which was used for the import of high pressure gas when an FSRU was berthed alongside. After an initial feasibility check, it was confirmed that the HP arm flow direction could be changed and that it could also serve as feed gas supply point.

Figure 13—HP loading arm connection

For the arm to be able to connect to the FLNG manifold, two modifications were required. First of all, the manifold flange, which was a standard 12" CL600 ANSI flange, needed to be replaced by a CL900 ANSI flange in order to be able to connect a dedicated spool piece supplied by the HP arm manufacturer.

Second, for the proper maintenance and daily checking of the HP arm, an access platform is needed around the HP coupler. This access platform was designed and installed on the FLNG at the conversion yard.

Implementation of lessons learned

During the initial commissioning conducted at the construction yard, several items were found which could be improved to allow for smoother operations. This was also one of the large advantages of performing the commissioning at the construction site. Improvements could easily be made while the FLNG was berthed along a jetty. This would have been much harder when the commissioning was completed, and the unit located at the operational site.

The most important upgrades which were made in preparation of the operations in Argentina are as follows:

- Improvements in the operational flexibility of the nitrogen generation system which is used for maintenance activities on the one hand, and refrigerant supply on the other hand
- Improvement in the operational flexibility of the boil-off gas compressors in order to run them more efficiently at various cargo tank pressure and temperature conditions
- Addition of maintenance tools to overhaul the refrigerant pumps
- Adding several service platforms for easier access to certain instruments and equipment
- Optimizing the several spare parts storage spaces on board
- Upgrade of the cryogenic piping insulation

Next to those relative large works, a lot of smaller works have been completed as well, to make it easier for the operators to run the FLNG plant or to further increase the efficiency of the operations. Some of these works required hot works on the process area. This would not have been possible, or at least would have been very complicated, when the FLNG was already in service.

Preparation for the dry tow

Even though the FLNG was designed to be dry-towed, the route and season was different as the one originally planned. An in-depth assessment was completed together with the heavy lift company, to ensure the FLNG could sustain the motions and accelerations which it was expected to undergo. Luckily, it was found that the entire supporting structure of the topside was rigid enough and capable of handling the revised transport motions and accelerations.

In a few areas, though, it was detected that there was a potential risk of overly high stresses on some large pipe supports and/or large pressure vessel nozzles. Appropriate mitigating measures were taken to ensure the stresses remained well below the acceptable limits. This was done through addition of temporary bracing and/or disconnection of piping from the nozzles.

Commissioning and start-up of Tango FLNG

Arrival on site

After a journey of 41 days, the Tango FLNG was set afloat again in front of the Bahía Blanca port in Argentinean waters from the HLV. A wet tow was used to transport the Tango FLNG to the jetty in Bahía Blanca where it will operate for at least the next 10 years.

Upon arrival at the jetty, the FLNG was temporarily moored. Installation of the permanent mooring lines began immediately as all connections and mooring lines were nicely prepared before arrival. It took only 11 days to install and make fast all fixed-length mooring lines.

In parallel with the permanent mooring installation, a second team on board was preparing the Tango FLNG to receive natural gas. This included amongst others following major works:

- In-depth inspection of all systems and equipment after the dry tow.
- Removing of the temporary bracing for the dry tow.
- Starting and testing the dual fuel diesel generators on MDO.
- Testing the firefighting system, water spray system and dry powder system to ensure it is ready for operations.
- Testing all safety systems (SIS system, ship shore connection, fire & gas detection, cryogenic spill detection, etc…)
- Filling of all lubricants and chemicals and testing the auxiliary equipment (compressors, cooling systems, lube oil systems, heat medium systems, etc.)
- Filling, washing and testing of the amine system.
- Installation and testing STS equipment.
- Installation of the gas turbine driver.
- Loading provisions and spare parts.
- HP arm connection, pressure and emergency disconnection tests.
- Drying of the cryogenic systems.

During the above activities, on the shore side, construction of the two amine treatment plants was completed, and were prepared for commissioning.

Commissioning & feed gas introduction

Tango FLNG was ready to receive natural gas before the onshore amine plants were fully commissioned. To optimize the overall schedule, the initial gas commissioning was already started with feed gas that contained higher CO_2 concentrations. Firstly, the flare ignition panel and flare pilots which are essential for safe operations, were tested on gas. With the flare pilots ignited the FLNG was ready to receive a feed gas flow, refrigerant inventory, and LNG cargo for cargo tank cool down.

Secondly, the feed gas custody metering unit and gas chromatograph were commissioned to have accurate measurements about the incoming gas quantity and its composition during the commissioning and production phase. With the delivered feed gas, the three dual fuel diesel generators could be tested and fine-tuned with natural gas as a fuel. In parallel, the entire process topsides up to the cold box were gassed in.

Once completed and stable power production for the barge was ensured, the start-up activities for the process plant could start. To start the gas pre-treatment systems heat is required. That heat is normally recovered from the hot exhaust gasses of the gas turbine that is powering the main refrigerant compressor. During an initial start-up the gas turbine is not yet in operation, but a duct burner is installed in the turbine waste heat recover stack to generate the necessary heat for the process plant start-up. After igniting the duct burner and heating the heat medium system to its operational temperature, the commissioning of the gas pre-treatment immediately started. The amine pumps started recycling the amine and water solutions and the amine reboiler and stripper were heated to their operational temperature.

To ensure the dehydrations beds dryness after the long lay-up period, three full regeneration cycles were performed for each bed. With the heat medium and pre-treatment systems operational, the gas turbine could be cranked and fired for the first time after its installation on site.

Simultaneously with the preparation of the pre-treatment systems, the TFLNG type-C cargo tanks where cooled by the visiting LNGC Gemmata and a minimum LNG heel was transferred to keep the cargo tanks in cold condition until the liquefaction plant started its LNG production. With this first cooldown and cargo transfer, the LNG sampling system and newly installed ship-to-ship equipment was tested for the first time. With LNG in the cargo tanks and its boil off gas, the four BOG compressors could be tested to ensure they were ready for operations when the liquefaction plant starts producing. Also, an internal tank-to-tank transfer was executed to test the three deepwell cargo pumps before the cargo tanks were fully loaded with LNG.

As a final step in the commissioning, the refrigerant inventory (propane, isopentane and ethylene) was loaded and stored on board by the use of Isotainers and the barge crane. The loading was completed at a suitable time during the process preparations when the isotainers were delivered at the jetty.

With the above activities completed, the Tango FLNG was ready to cool down the cold box and to start the LNG production.

Thanks to the close cooperation, communication, and planning between all involved parties the amine shore plants were ready at almost the same time the TFLNG could start the liquefaction plant.

Start-up

When all checks were completed and with the shore amine plants running, Tango FLNG fired its gas turbine and started to pack the refrigerant loop to cool down the cold box. This cooling down operation is very delicate and needs to be undertaken with great care. If the cooling down is too fast, the thermal stress on the cold box cores will be too high which could cause damage. On the other hand, if the cooling down operation is too long, too much natural gas is wasted which needs to be avoided. Keeping a stable and balanced cool down rate is the essence of a successful cooling down operation.

Once the cool down is completed, LNG is produced and sent to the cargo tanks. The production rate is then gradually increased while all process control parameters are finally tuned.

The Tango FLNG has a limited storage capacity of 16,000 m^3 which will be filled within 5 days at full production capacity. For this reason, the LNGC Fuji LNG was moored alongside the Tango FLNG during the cold box cooldown. The ship-to-ship equipment was connected in preparation to transfer the first produced LNG batch to the LNGC Fuji LNG.

During the first days of operation, the liquefaction plant was fine tuned to have a stable liquefaction process and to meet the guaranteed production figures.

Performance testing

A performance test was executed to present to the end Customer that the Tango FLNG could meet the following criteria:

- Actual production rate is equal to or higher than the guaranteed production rate.
- Uninterrupted stable LNG production for at least 72 hours.

– Saleable LNG is produced.
– Fuel consumption is within the guaranteed limits.

During the performance test all required parameters were recorded by an independent third party to objectively assess if the above criteria were met. The performance test commenced on June 2nd, 2019 and was completed June 5th, 2019. All four criteria were successfully achieved and the Tango FLNG went officially into commercial operations, continuing its production to load the Fuji LNG.

Conclusion

Tango FLNG which was built and designed to operate on a gas field in Colombia, could swiftly be prepared for operations in Bahía Blanca, Argentina. In a record time, the FLNG was modified, moved to the operational site, and started up to turn Argentina from an LNG importer to an LNG export nation.

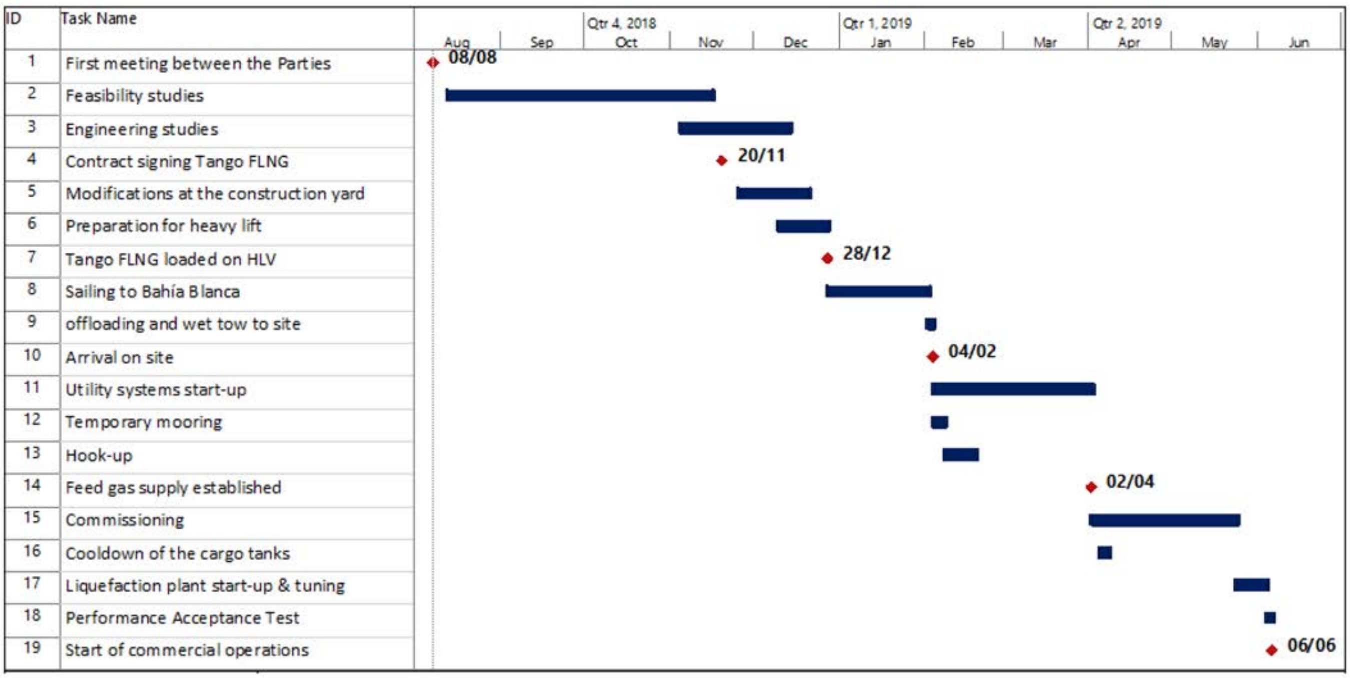

Figure 14—Tango FLNG schedule

The FLNG design has proven to be very flexibly and robust for external changes. The process topsides are performing up to expectations under a large variety of feed gas conditions and compositions.

Being built under protected conditions at traditional offshore yards, the FLNG can be delivered on time and on budget. After a transportation to site, the commissioning and start-up can go smoothly when this is well prepared. The combination of such a robust timeline and flexibility of operations make the FLNG concept very reliable and competitive compared to the more traditional onshore plants.

Abbreviations

BOG : Boil-Off Gas
BV : Bureau Veritas
CFLNG : Caribbean FLNG
EPCIC : Engineering Procurement Construction Installation and Commissioning
FID : Final Investment Decision
FLNG : Floating LNG Liquefaction plant
FSRU : Floating Storage and Regasification Unit

FSU : Floating Storage Unit gpm: gallons per minute
HLV : Heavy Lift Vessel
HMPE : High Molecular weight Poly-Ethylene
HP : High Pressure
IMO : International Maritime Organization
LNG : Liquefied Natural Gas
LNGC : LNG Carrier
LPG : Liquefied Petroleum Gas
MBL : Minimum Breaking Load
MDO : Marine Diesel Oil
MT : Metric Ton
MTPA : Million Metric Ton per annum
NGL : Natural Gas Liquids
PA : Poly-Amide
ppmv : parts per million volumetric
QRH : Quick Release Hook
SMR : Single Mixed Refrigerant
SIS : Safety Instrumented System
STS : Ship-To-Ship
TFLNG : Tango FLNG
TRS : Temporary Regasification Skid

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