The Yamal liquefied natural gas (LNG) facility is an integrated project located north of the arctic circle on the Yamal Peninsula in northern Russia. The project consists of three LNG trains that produce a total of 16.5 million tonnes per annum (mtpa), along with substantial infrastructure that includes extensive living accommodations, power generation utilities, an ice-free deep-water sea port, and an international airport.

The geopolitical context, project finance and the extraordinary human endeavor of a project of this size in the arctic were challenges rarely seen in the past. As this is the northern-most operating LNG facility in the world, this paper will cover the achievements of the project, including developing the largest Air Products AP-C3MR™ LNG Process train, constructing a highly modularized project in a harsh environment and successfully loading the first cargo during the polar winter night.

This paper focuses on technological features that had to be carefully managed, for example:
- Successfully implementing a new high availability, maximum capacity, parallel C3/MR compressor arrangement that required extensive collaboration between the main contractor, compressor supplier, plant operator, and process licensor to achieve the 5.5 mtpa capacity per train.
- Ethane and propane refrigerant make-up could be produced early due to the turbo-expander based NGL recovery unit.
- The commissioning and defrosting, under conditions where water exists only as a solid, also required adapting the warm climate methodology.
- Managing hydrates.
- Air cooling, in an environment with a very large winter-to-summer range (-40°C to +10°C).

The paper will conclude by describing the successful operation and performance test of all three Yamal LNG trains.
Yamal LNG, a mega LNG project in the far north...

Located in the Arctic Circle in the northeast corner of the Yamal Peninsula in Western Siberia on a large parcel of land jutting into the Kara Sea, Yamal LNG is one of the biggest LNG projects in the world and the largest application of modularization ever undertaken. The LNG facility will utilize the resources of the South Tambey field estimated at 926 billion cubic meters (BCM) (32.7 trillion cubic feet) and recognized as one of the world’s biggest gas reserves.

The Yamal LNG plant was built in three phases, each featuring a 5.5 mtpa process train. Yamal LNG is producing a total of 16.5 mtpa of LNG and up to 1.2 mtpa of gas condensate at full capacity, which will be shipped to Asia-Pacific and European markets.

The pioneering project has been executed by the Yamgaz joint venture led by TechnipFMC with JGC and Chiyoda for JSC Yamal LNG, a consortium owned by Novatek, Total, CNPC and Silk Road Fund, and uses the Air Products AP-C3MR™ liquefaction process. The main refrigeration compressors and Frame 7 drivers have been supplied by Baker Hughes, a GE Company.

The facility has been designed for arctic conditions that require special construction materials such as structural steel that is resilient below -50°C and a unique pile-based foundation system that includes a permafrost preservation plan. Because of the extreme climate conditions, including a three-month-long polar night, a frozen sea seven to nine months out of the year and temperatures dropping to -57°C, the joint venture opted for modular construction using 10 fabrication yards in southeast Asia and high-level logistics to ensure shipments to Russia.

Despite all the challenges and thanks to innovative thinking and careful project planning, the Yamal facility started production at the end of 2017 as planned. A year later, the third and last train has been successfully started too, while the Train 1 and 2 were steadily and reliably producing at and sometimes above their name plate capacity.

The Front End NGL Recovery unit

The natural gas of Yamal LNG is lean. However, prior to liquefaction it is necessary to remove heavy hydrocarbons (pentane and heavier components including aromatics such as benzene) to prevent crystallization and plugging in the cryogenic section of the liquefaction plant. Compared to the former conventional solution to use an integrated scrub column within the liquefaction unit, the Front End NGL Recovery unit is more selective to remove heavies when the feedstock is very lean and increases refrigerant make up extraction rate (ethane and propane) from lean gas. This highest selectivity is achieved by decoupling the operating pressures of the NGL extraction and the liquefaction unit. Indeed, the NGL Extraction is achieved after a significant reduction of feed gas pressure, while treated gas is recompressed prior to being liquefied (refer to figure 2).
In addition, the decoupling of the operating pressures allows the liquefaction to be carried out at much higher pressure than possible with integrated scrub column scheme, even liquefying the natural gas at supercritical conditions. Such increase of liquefaction pressure significantly improves the efficiency of liquefaction [1] which could either result in additional LNG production or reduce the CAPEX of the liquefaction unit for a given LNG throughput [2].

In the context of the Yamal LNG project, the higher liquefaction pressure (around 70 bar) reduces the power requirement of the refrigeration compressors for a given LNG production. The extra power available on the helper/motors of the gas turbines driving the refrigeration compressors has been used to maintain a high level of production during average and summer conditions, leading to a flatter LNG production along the year closer to the maximum hydraulic capacity of the plant (110%) sized for the winter conditions.

The Front End NGL Recovery unit implemented for the Yamal LNG project is based on the TechnipFMC Cryomax®-SRE (Single Reflux Ethane) process, part of a portfolio of NGL recovery processes for C2+, C3+, C5+ or variable C2+ recoveries. It is a turbo-expander NGL extraction process with an additional reflux of NGL. Figure 2 illustrates the flow scheme of this process. The main reflux of the extraction column (demethaniser) is provided by a portion of the cooled feed gas which is liquefied against the cold overhead gas of the demethaniser. The main reflux allows the process to reach the C2+ extraction target but is not selective for benzene removal as it still contains heavies. A second reflux is provided as top reflux from a mixture of NGLs produced in the fractionation unit to wash the overhead gas and ensure the tight pentane plus and aromatics specification required for the liquefaction process.

During the start-up of LNG train 1, other advantages of the Front End NGL Recovery unit have been crucial. The decoupling of the NGL extraction from the liquefaction unit has facilitated the start-up sequence. While the defrosting of the liquefaction unit was under completion, several steps of start-up have been completed, including start-up of NGL extraction and fractionation and cold gas from demethaniser overhead has been used to start the cooldown of the LNG rundown lines.

The selectivity of the C2+ extraction with the Front End NGL Recovery has been decisive. Indeed, availability of upstream wells have been phased and the plant has been started against lean gas. Propane refrigerant was available through propane import, however ethane refrigerant had to be produced from the feed gas. Even under
lean gas conditions, the ethane has been produced relatively rapidly to fill the mixed refrigerant loop and to produce LNG initially at very low rate to cooldown the LNG tanks and rapidly at half and full LNG production. Although it was not required for the very first start-up of Yamal LNG, the NGL recovery also allows production of propane refrigerant before the refrigerant compressors are available.

During the first year of operation of the Yamal LNG plant, including operation of Train 1, Train 2 and start-up of Train 3, the NGL Extraction process has also demonstrated a very high flexibility against various upset conditions. The NGL Extraction has been verified as very stable against variations of feed gas composition thanks to the key operating parameters of the unit which do not require much adjustments (e.g. operating pressure of demethaniser remains constant versus various feed gas quality).

The unit was initially started at reduced throughput on Joule-Thomson mode before start-up of the turbo-expander. Such severe turndown conditions have not jeopardized the efficiency of the unit including the NGL and heavies extraction as well as its stability, even though the demethaniser was operated at higher pressure than initially planned during the design phase.

The AP-C3MR™ Liquefaction Process

Air Products’ AP-C3MR™ LNG Process was selected for the Yamal LNG project. The AP-C3MR LNG Process is the workhorse of the LNG industry and is used in over 90 operating LNG trains. Refer to figure 3 below for a simplified diagram of the AP-C3MR LNG Process.

The AP-C3MR liquefaction process cools and liquefies natural gas using two refrigeration loops. Natural gas is fed to the precooling section where it is cooled from ambient temperatures to approximately -35°C by a three-stage propane refrigeration loop. The pre-cooled feed gas then enters the Main Cryogenic Heat Exchanger (MCHE), which is a coil wound heat exchanger (CWHE). The natural gas is then liquefied using a mixed refrigerant (MR) which is a combination of nitrogen, methane, ethane, and propane. The composition of the MR can be adjusted to maximize the process efficiency. Finally, the LNG exits the cold end of the MCHE before being piped to the LNG storage tank. For Yamal LNG, two GE Frame 7 gas turbines were selected to drive the refrigerant compressors.

In the MR refrigeration loop, the high-pressure MR is cooled by propane to approximately -35°C, and it partially condenses. The MR is separated in the HP MR separator into MR liquid (MRL) and MR vapor (MRV). The MRL enters the warm end of the MCHE, where it is subcooled. The MRL is removed at an intermediate point of the MCHE, reduced in pressure and sent to the MCHE shell side. The MRV enters the warm end of the MCHE where it is liquefied and subcooled. The MRV exits the cold end of the MCHE before being reduced in pressure and returned to the shell side. The MRV and MRL boil on the shell side, providing the refrigeration to liquefy and subcool the incoming natural gas and MR. Superheated vapor MR exits the warm end of the MCHE before being compressed in a two-stage centrifugal compressor, consisting of a Low Pressure (LP) and High Pressure (HP) MR compressor stage.

Figure 3: Air Products’ AP-C3MR™ LNG Process
Air Products has built over 120 coil wound heat exchangers (CWHE) for LNG service, but Yamal LNG was the first AP-C3MR train in an arctic environment [3]. The Yamal LNG MCHE was installed into a modularized structure at site requiring coordination between Air Products’ manufacturing team and TechnipFMC’s site construction team. In addition, the Yamal LNG MCHE needed to be designed for arctic conditions. In arctic design, Air Products takes into account the snow and ice that could build up on the exchanger and associated platforms during the long winter. Additionally, sub-zero temperatures present the challenge of designing the shipping saddles and lifting equipment that can withstand cold temperatures avoiding embrittlement and the resulting fracturing that could occur. While these challenges are new compared to equatorial plants, they are easily managed during design. [6]

In addition to the mechanical challenges, Yamal LNG initially posed process design challenges as well. Prior to Yamal LNG, the largest operating AP-C3MR process had a capacity of 5 million tonnes per annum (mtpa), while Yamal LNG would be designed for a capacity 10% greater than previous plants. To increase the liquefaction capacity, Air Products manufactured the largest diameter CWHE along with the single largest bundle by weight to date. In addition to increasing size of the MCHE, higher production capacity was accomplished through the continuous improvement of the CWHE productivity over the last 40 years while maintaining the hydraulic conditions and internal flow regimes for the CWHE within Air Products’ operating experience to minimize technical risk. Yamal LNG also continues Air Products’ successful experience in designing for feed pressures over 70 barg. [7]

**Refrigerant Compressor and Driver Arrangement**

As discussed above, two GE Frame 7 gas turbines were selected to drive the refrigerant compressors for Air Products’ AP-C3MR liquefaction process. Typically, the precooling power is 30 to 40% of the total power consumption. However, due to the colder inlet temperature in the arctic, the precooling power is less, approximately 25% to 30% of the total refrigeration power. To maximize LNG production, it was necessary to select a machinery arrangement that was able to fully utilize the available driver power.

Over fifteen years ago, Air Products pioneered the first AP-SplitMR® machinery configuration, which evenly splits the mixed refrigerant compression power between the two gas turbine drivers by placing the low pressure and medium pressure mixed refrigerant compressors on one driver and the propane compressor and high pressure mixed refrigerant compressor on the second driver. This configuration is shown below in figure 4. At design ambient conditions, this arrangement balances the refrigeration power to maximize production using all the available driver power.

![Figure 4: Air Products Split MR® Machinery Configuration for AP-C3MR (not applied for Yamal LNG project)](image)

One challenge of this configuration is that ambient temperature changes both the available gas turbine power and the required power split between propane and MR. In an arctic climate, the ambient temperatures can vary dramatically. It is not uncommon to experience seasonal temperatures as warm as +10°C in the summer and as cold as -40°C in winter, while seeing diurnal or weekly swings as large as 20°C. This wide range of ambient temperatures can result in unutilized refrigeration power on one of the gas turbines as the ambient temperature...
moves away from design ambient temperature. For example, in summer, more precooling refrigeration is needed, which increases the required propane compressor power, while the available power on the gas turbine driver decreases due to the higher ambient temperature. This results in the turbine driving the propane and HP MR compressors to consume the maximum available driver power, while the gas turbine driving the LP and MP MR compressors is not consuming the maximum available power. Conversely, in the winter, less precooling is needed, causing the propane compressor to require less power, while the gas turbine driving the LP and MP MR compressors is consuming maximum available power to maximize LNG production. The impact of this shift in refrigeration duty is that there is typically unutilized gas turbine power on one driver as the ambient temperature moves toward either temperature extreme. This is illustrated below in figure 5.

Figure 5: Driver Power Utilization at Warm and Cold Ambient Temperature

To maximize LNG production, a 2 x 50% machinery configuration was selected for Yamal LNG and is shown below in figure 6.

In this configuration, the gas turbine power simply shifts between the propane and MR compressors without any action needed from the operators or the control system, so the all the available gas turbine power can be used 100% of the time.

Using a 2 x 50% machinery configuration reduces the flow through a single compressor, while maintaining the same total refrigerant flow to the liquefaction unit. As an added benefit, parallel compressors offer higher LNG plant availability as a trip of either gas turbine will not trip the entire LNG plant. Instead of shutdown, the plant operates at reduced throughput when one compressor string is offline. This means the LNG plant spends more time producing LNG throughout the year, which minimizes that stress on equipment due to upsets or plant trips. Parallel compressor strings also provide higher turndown capability of the compressors without having to recycle as one compressor string can be shut down during turndown operation [5].

Refrigerant Turbocompressor Technology

The location and challenges posed by the Yamal LNG project required proven robust and reliable solutions. The refrigerant turbocompressors consisting of the Frame 7 gas turbine, three compressor bodies and the starter/helper motor was not a novelty in LNG plants from a mechanical configuration point of view as such a configuration has been running successfully for several years in Western Africa.
The AP-C3MR process with 2 x 50% machinery configuration requires two additional compressor bodies compared to the traditional AP-SplitMR solution, but at the same time has characteristics that enhance the rotordynamic and fluid-dynamic performances of the compressors.

In case of the 2x50% arrangement, the 50% gas flow that each of the compressors handles reduces the axial dimensions of each of the compressor stages, as well as the size of the nozzles and volutes. As a result, the bearing span is lower than a traditional 1x100% configuration. At the same time, the head needed for the refrigeration process is the same for both solutions which means having practically identical impellers and casing diameter, which allows the bearings and the dry gas seals to be very similar in the two cases. The combination of these items leads to increased stiffness of the shafts. Figure 7 shows that the Propane and Low Pressure MR compressor casings are well within the BHGE reference limits (the diagram refers to horizontally split casings). The High Pressure MR compressor is not represented in the diagram as it has a vertical split casing, but BHGE has many similar compressors in operation.

Even from a torsional point of view the 2 x 50% machinery configuration does not present any significant challenge compared to projects developed in the past (same number of compressor casings on the same shaft line, similar driver on one side and similar helper / starter motor on the other). Based on this and given that the compressor axial dimensions are reduced, it can be concluded that the 2 x 50% machinery arrangement has an overall rotordynamic behavior that is more favorable compared to the 1x100% compressor arrangement.

The 50% gas flow results in approximately 30% smaller diameter compressor nozzles and smaller diameter process piping which improves the ability to route piping. It is common practice to have a minimum straight run of pipe diameter before each compressor suction. For Yamal LNG, the compressor nozzles have a bottom position and smaller diameter piping helps to reduce the turbocompressor center line position with relevant benefits in terms of foundation height and ease of maintenance.

For most large LNG plants, it is typical to carry out a full load string test of the turbocompressors to demonstrate that they deliver the performance expected and confirm the soundness of the overall design, manufacturing and assembly processes. In the case of the 2 x 50% machinery configuration it may be sufficient to test only one string while it would be necessary to test both compression strings for traditional 1x100% arrangements.

For very large baseload LNG plants, such as Yamal LNG, the required refrigerant compressors’ aerodynamic conditions for 1x100% of refrigeration demand may be at the limits of the referenced refrigerant compressor designs and at those operating conditions the compressor can not deliver the high compression efficiency expected from modern compressor designs.

Two key compressor design parameters are:
1) Tip (or Peripheral) Mach number: ratio of the impeller tip velocity to the sonic velocity (referred to the gas conditions at the impeller inlet)
2) Inlet flow coefficient: dimensionless parameter that indicates the general impeller geometry and flow capability.

The 2 x 50% machinery configuration improves the aerodynamic conditions in the compressors such that the operating points are well centered within the BHGE referenced compressor scattered plot diagrams and the compressors operate at their optimum performances. Figures 8, 9 and 10 show the compressor operating points for a 1 x 100% machinery configuration and a 2 x 50% machinery configuration.

*Figure 8 – BHGE References of the LP MR Compressor Impellers for 1x100% and 2 x 50% Machinery Configuration*

*Figure 9 – BHGE References of the HP MR Compressor Impellers for 1x100% and 2 x 50% Machinery Configuration*
Figure 10 – BHGE References of the C3 Compressor Impellers for 1x100% and 2x50% Machinery Configuration

A challenge of the 2x50% machinery solution is represented by the need for identical performance curves for the same compressors of the two strings. While the two compressors are designed for the same operating point, if for reasons mainly linked to manufacturing and/or assembly of the compressors the actual performance curves are not identical, a situation like the one shown in figure 11 may occur.

Figure 11 – Performances of Compressors Working in Parallel

In this case, during the plant operation, the two parallel compressors would run at different operating points which may not be preferred from a process and operations perspective. Adjusting the compressor operating point requires acting on at least one of the two parallel compressors (for instance by inlet throttling valve) to bring both compressor strings to the same conditions, but this means adding some losses to the process which may impact efficiency. This highlights the importance of the construction and assembly processes to guarantee a high degree
of repeatability of identical machines, processes that BHGE has developed and optimized over many years for this class of machines.

**Refrigerant Turbocompressor Operability**

While there are clear benefits to the 2 x 50% compressor arrangement, the arrangement is not without challenges. Parallel compressors require managing compressor performance to prevent undesired operating conditions such as surge or choke, particularly at turndown. In addition, systems and procedures are needed to maintain stable operating of the entire liquefaction unit when one compressor string (inevitably) trips and is subsequently restarted. Extensive dynamic simulation work was completed by Air Products, TechnipFMC and BHGE to ensure the operability of the parallel compressor strings.

To provide the necessary operational flexibility, the following features were included in the compressor designs:

1. Propane liquid quench lines
2. MR cross-connection lines that connect the discharge of the one MR string to the suction of the other MR string
3. Inlet throttling valves on the first stage of the MR compressors and all three side-streams of the propane compressors
4. Propane cross-connection line that connects the propane desuperheater outlet of one propane string to the LP suction of the other propane string

Before bringing a second propane compressor online, the suction temperature of each sidestream must be cooled to match the performance of the operating compressor string. To facilitate this with minimal impact to the operating liquefaction unit, propane liquid quench connections were provided to cool the suction of each sidestream. These connections take subcooled liquid propane from the propane subcooler and flash the propane to the sidestream operating pressure before mixing the quench stream with the anti-surge flow to each sidestream. Automatic temperature controllers adjust the flow of liquid propane which slowly cools the propane compressor suction to match the operating string compressor performance.

In addition to propane liquid quench, the propane compressors also feature cross-tie connections that connect the propane desuperheater outlet of one propane string to the LP suction of the other propane string. This connection can be used during the tie-in process to cool the LP suction of the propane compressor. This is accomplished by opening the cross-connection valve on the discharge of the offline propane compressor. This sends flow from the discharge of the offline propane compressor loop to the online propane compressor. Depleting the inventory of the offline compressor loop pulls cold gas from the propane kettles in to the offline compressor loop, slowly cooling the suction of the offline compressor. The cross-tie connection can also be used to de-pressure and recover refrigerant from the propane compressor prior starting the gas turbine. The propane compressor cross-tie connections are show below in red in figure 12.
Similar to the propane compressor, the LPMR compressor suction is cooled to match the operating performance of the on-line MR compressor string. Cooling the LPMR compressor suction allows the offline compressor to be tied-in to the process by increasing the delivered head of the compressor to allow the offline compressor discharge pressure to match the operating system pressure. The tie-in process is helped by operating the offline compressor string on the surge control line which also increases the delivered head of the compressor. The MR cross-connection line, which connects the discharge of the offline compressor loop to the suction of the online compressor, is used to cool the LPMR compressor suction. To cool down, the cross-connection valve is opened, which draws flow from the discharge of the offline MR compressor loop. Depleting the inventory of the compressor loop pulls MR from the warm end of the MCHE in to the offline compressor loop. Cold gas from the MCHE slowly cools the suction of the offline LPMR compressor. As the compressor cools, the delivered head increases until the offline compressor performance matches the online compressor performance allowing the offline compressor to be tied-in to the liquefaction process. As MR flow and LNG production are increased, both compressor strings will contribute to the total MR flow. The MR compressor cross-tie connections are show below in red figure 13.

Inlet throttling valves (ITVs) are provided on the MR and propane compressor to balance the parallel compressor loads when the compressors are operating on the surge control line and the anti-surge valves are open. In addition, the MR ITV provides load-shedding capability when one gas turbine trips. When a gas turbine trips during normal operation, the remaining compressor string must continue to operate. The immediate effect of a single...
compressor trip is that the suction pressure to the operating compressor will increase due to the continued vapor generation in the MCHE. It is necessary to reduce the mass flow that is supplied to the remaining compressor string to prevent overloading the driver and low speed trip of the remaining string. This is accomplished by partially closing or throttling the ITV to limit the mass flow in to the compressor. This accumulates pressure in the MCHE without increasing the compressor suction pressure and overloading the driver. The MR circulation rate is reduced to match the capacity of the surviving compressor string by closing the JT valves. As the MR loop stabilizes, the inlet throttle valve is slowly re-opened to 100%.

As part of initial plant operation, the ITVs were found to provide a similar benefit if the helper motor on either string tripped. Normally the trip of a helper motor would result in a low speed trip of the gas turbine due to the sudden increase in load on the gas turbine. A gas turbine trip is avoided by automatically throttling the ITV which quickly reduces the load on the gas turbine.

The design and control strategy put in place for parallel MR and propane compressor operation successfully ensured smooth, stable parallel string start-up and normal operation. The control strategy has successfully prevented a cascading trip of the 2\textsuperscript{nd} string upon one string trip ensuring the uninterrupted operation of the liquefaction plant.

As mentioned above, there is an MR cross-connection line, which connects the discharge of one compressor string to the suction of the other compressor string and a propane cross-connection line that connects the propane desuperheater outlet of one propane string to the LP suction of the other propane string. For a single shaft gas turbine, such as a GE Frame 7, it is typically necessary to vent the refrigerant inventory in the compressor loop prior starting the gas turbine to minimize the torque needed to start the gas turbine driver. The cross-connection lines can be used to vent the refrigerant from the propane and MR compressors and recover the refrigerant back in to the operating compressor string to minimize losses and reduce flaring.

**Commissioning in a cold climate, an aggregation of new challenges**

The commissioning of an LNG plant is usually a complex exercise consisting of many critical tasks, which includes flushing the auxiliary system of the large compressors and gas turbine, checking several thousand instrumentation loops, confirming the tightness of large system and defrosting the cryogenic section to single digit ppm levels of moisture. Completing these activities in one of the most remote places on earth, combined with unfriendly weather, was an incredible challenge. As an example of these challenges, imagine trying to vaporize water at freezing temperature!

A lot of advanced planning and detailed organization have been completed to develop solutions that not only made these operations feasible, but also efficient enough to meet the LNG production milestone.

Maximizing pre-commissioning activities at the module fabrication yards in Asia was a key success factor. In particular, this created opportunities to clean, dewater and pre-dry the pipework in anticipation of the cold weather conditions at Sabetta. High Pressure Leak Tests (HPLTs) were conducted with nitrogen at the yards, shortening the duration of on-site HPLTs that were then only required for the remaining stick-built sections.

Process lines in the propane and MR refrigeration loops have been fitted with insulation to maintain defrost gas warm enough to properly defrost these systems, even if insulation was not required for operation purposes. Similarly, air coolers, located on the refrigeration system, have been covered by temporary tarpaulins to minimize heat losses during defrost.

Circulating warm air through the process has also been used to dry as much of the system as possible while final construction activities were completed. In addition to reducing the usage of defrost gas, it also shortens the schedule by permitting the drying to start while construction was still being completed.

While each LNG train includes a turbo-expander based NGL recovery unit, which enhances the recovery of ethane and propane used to make up refrigerants to the propane and MR systems, it was decided to import the first inventory of propane for Train 1. This allowed the line-up of the propane compressor and propane cycle to be completed in parallel with the final defrosting operation of the liquefaction section, saving precious days in a tight schedule.
Plant Start-Up, Initial Operation and Performance Test

The specific measures taken for the commissioning plus the extraordinary commitment of all the teams on site resulted in the first drop of LNG production only 28 days after gas-in for the first liquefaction train.

Yamal LNG Train 1 started LNG production in November 2017. Initially the plant was operated stably for several weeks on a single compressor string to cooldown and build inventory in the LNG storage tanks. The first cargo was shipped from Train 1 on December 8, 2017. Before the end of 2017, Train 1 smoothly transitioned to two compressor string operation and was ramped to design capacity and achieved over 100% of design LNG production. Train 1 successfully passed its performance test by the end of February 2018 with LNG production and liquefaction efficiency targets comfortably achieved. The extensive reviews and engineering analysis performed as part of the project helped to make the parallel compressor operation a success transitioning between single compressor operation and parallel compressor operation can be accomplished with ease.

For Train 2 and Train 3, the availability of large quantities of warm dry gas, along with ethane and propane refrigerants from Train 1 have allowed to significantly reduce this already short start-up time. The first drop of LNG was achieved in less than 10 days for both Trains 2 and 3, demonstrating the high level of quality of the design, construction, commissioning and operation.

The first cargo was shipped from Train 2 on August 9, 2018. Train 2 successfully passed its performance test in early September 2018 and was followed by the successful performance test of Train 3 in December 2018.

As of the end of 2018, Yamal LNG has shipped over 100 LNG cargoes and over 8 million tonnes of LNG, with all 3 LNG Trains operating at full capacity.
REFERENCES


