SHIPPING LNG FROM AN ARCTIC LNG PLANT: SOME MARINE CHALLENGES

by

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ABSTRACT

Novatek, Total, CNPC and Silk Road Fund are partners in the Project named Yamal LNG located on the Yamal Peninsula (Russia) to produce the huge gas reserves of South Tambey fields (about 927 BCM of natural gas). The LNG Plant is located in Sabetta on the west bank of the Ob River, North of the Arctic Circle. The extraction of gas and the building of a liquefaction plant on permafrost in these regions seem to be less challenging than its transportation under LNG form, from the production plant to the markets, as the LNG & gas condensate carriers have to use the Northern Sea Route, in ice-covered waters, for about nine months a year. A year-round accessible and operable Port therefore had to be built.

To evacuate the 16,5 Mtpa LNG and 1,2 Mtpa of gas condensate production from the Liquefaction Plant, the shipping solution chosen to ensure the safe and reliable maritime transportation year-round was to build a fleet of up to 15 Arctic LNG carriers, with sufficient ice-class notation (Arc7) and ice-breaking capability to operate without the assistance of the Russian ice-breakers in the conditions of Barents and Kara seas. They will operate independently year-round to North-West Europe where the cargoes will be sold or transferred unto conventional LNG carriers at selected trans-shipment terminals.

To accommodate these vessels in Sabetta, the new Port had to be designed in such a way that it is accessible and operable year round. This means that compared to conventional marine facilities, the focus has been put on the ice management of the navigational waterways – dredged river channels and Port access channels, the sheltering of the jetties of the Port by ice protection barriers, the jetties and quays designed to sustain the ice loads, their winterization and their ice management through brash ice management system, and the sizing of a support fleet in order to ease the operations in the ice.

The lessons learnt during the construction phases of the Plant – dredging of channels, delivery of materials for site preparation and civil works during open water season and in the winter, building the marine offloading facilities for delivery of the modules of the Plant, steps to the final design of merchant ice-breaking ships, construction of a future international airfield, current and future logistics solutions for using the Northern Sea Route for the Project purpose – and much more challenges are described in the paper.

The first Ice-breaking LNG Carrier was delivered in 2016 and has carried-out her ice-trials successfully in March 2017 ; the first liquefaction train of the Yamal LNG Project started in December 2017 and in March 2018, the first million tons of LNG was safely delivered to the gas buyers.

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1. INTRODUCTION

The Yamal LNG Project is definitely a pilot project for Russia: initiated by a decree from the Russian government on October 11th 2010, which promoted the integrated development of the LNG Industry, it also granted some exemption taxes on producing and exporting LNG and condensates, participating in the building of new infrastructures such as the marine Port and its access, an airport, and providing all necessary framework to expedite the materialization of the Project.

The final investment decision was taken in December 2013 by the sponsors of the Project and after four years of construction, the first train of production started in December 2017. The two other trains will successively be added with a one-year timelap to reach the full production of 16,5 Mtpa of LNG and 1,2 Mtpa of gas condensates. The milestone of the first million tons of LNG produced was announced on March 2018; today Sabetta Port is an international maritime port, with an international airport, in the North of the Arctic Circle (Fig.1).

Figure 1: The location of the Yamal LNG Project, North of the Arctic Circle
Courtesy of Yamal spg

2. AN INTEGRATED PROJECT

2.1 The general scheme for shipping the LNG and gas condensates

Due to the location of the Liquefaction Plant on the Yamal peninsula, the shipping solution for reaching European and Asian markets on a safe, regular and sustainable basis is to consider using the Northern Sea Route, to the West all year-round and to the East during the open-water season (i.e. five months per year approximately).

A dedicated fleet of Arctic LNG carriers with sufficient ice-breaking capabilities to overcome the annual tear ice of the Kara and Barents seas and sufficient ice-class notation to be authorized to navigate independently by the Northern Sea Route Administration had to be built. After numerous simulations and taking the assumptions from the marketing, 15 Arc7 LNG Carriers of about 170,000m^3 of cargo capacity have been ordered to deliver the total production of the three trains, that is 5,5 million tons each per year.

For the deliveries to Asian gas buyers during the ice congested period of the eastern seas of the North East Passage, a trans-shipment of the cargo between Arc7 LNG carriers and conventional LNG carriers has been considered in Europe (Fig.2).

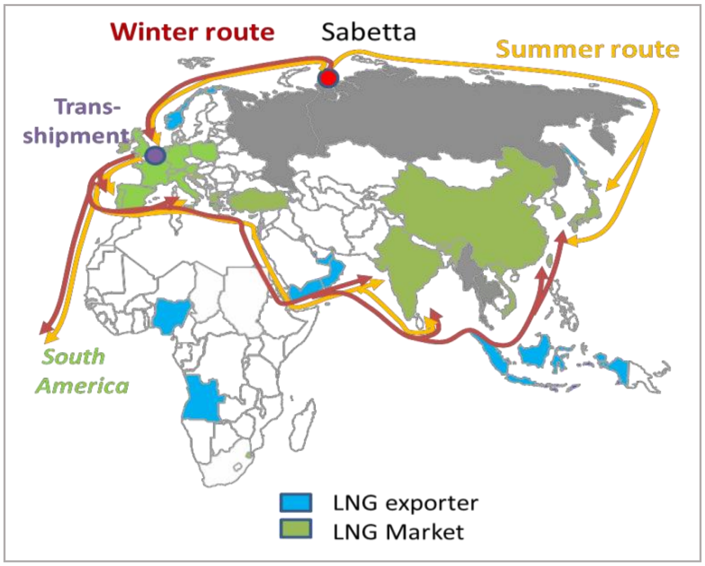

Figure 2: The transportation scheme for the LNG products from Yamal Peninsula to Gas Buyers' markets

2.2 The location of the Plant

The choice of the plant location has been dictated principally by the situation of the gas fields of South Tambey (gas reserves 2P PRMS: 926 BCM on 31.12.2013) : the Plant and the Port had to be as near as possible to the reserves to avoid any long pipeline feeding the Plant. A small port in Sabetta already existed, created by pioneers in the 1980s to accommodate geological survey teams. In the year 1985, some trials had been carried out by experimental expeditions to prove the feasibility of navigation in the ice of the Kara sea in the area (ARCDEV Program) (Fig.3).

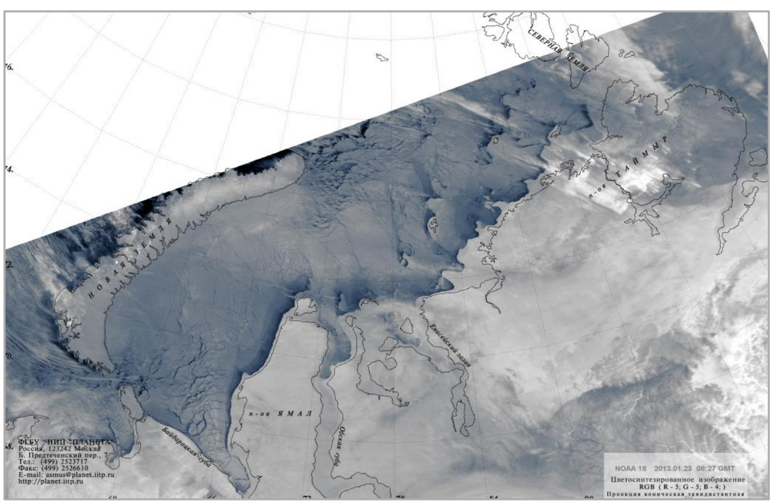

Figure 3: The Yamal Peninsula with the Ob River mouth in fast ice (February 2013)
Courtesy of AARI

During the first years of site preparation, due to the remote location and the absence of suitable year-round overland transportation infrastructure, most of the raw materials and equipment required were delivered to site by sea, using the Northern Sea Route. The old way of unloading equipment and materials on the ice and building roads (Fig.4) was used in order to start building the Marine Offloading Facilities (MOF) of the

Port; it also allowed to collect additional data on local ice conditions during the course of the vessels' voyages and during the year in the area of the future Port .

Three different ice periods have been identified off Sabetta: a “freeze-up” period during which ice first forms and thickens but is still mobile (starting beginning of October); the “fast-ice” period during which the ice is not moving but is still growing (about 3 weeks later); the “break-up” period with thick floes drifting in the Ob Gulf and which could invade the Port (about three weeks in July). This is representative of a typical winter. At the end of the ice period, maximum estimated ice thickness can be up to 2,5 meters at the mouth of Ob River.

Figure 4: Unloading on ice with the multipurpose vessel SA15, offshore Sabetta (courtesy TOTAL)

The MOF will allow, later on, to accommodate the heavy lift vessels and modules carriers delivering the components of the Liquefaction Plant. The main philosophy to build the Plant is a modular concept, with most of the modules assembled in East Asia; this would reduce the impact of the polar environment on the construction process, enable the best use of available labor, and take into account the remoteness and limited access to the site. The modularization allows construction works to be carried out simultaneously in several locations, with the modules being delivered and connected on site, hence minimizing hook-up, pre-commissioning and commissioning activities at the site.

3. THE CHALLENGES OF THE PORT AND OF ITS ACCESS

3.1 The North Access channel and Port channel

From the origin, the small Port of Sabetta is located on the West Bank of the Ob River (71°15'N,72°E) For large ships with a draft of about 12,5m to access the location, a channel of about 50 km had to be dredged in the North part of the river. How to design this channel for its use in open water and in ice conditions ?

In ice season, after each passage of a vessel, the ice will quickly grow back in the open track, meaning that after several passages, the ice thickness in the channel will be bigger than natural ice growth thickness, resulting in higher resistance for the ship. After a period of time, the channel becomes clogged and non-navigable; another track has to be used.

Several trials have been carried out in Lula (Sweden) in order to assess the phenomenon of brash ice formation in broken channel with an ice-breaker in order to provide data to correlate and validate some brash ice growth models (Fig.5 & 6).

Figures 5: The formation of brash ice studied using ice breaker in a channel

The final design of the North Access Channel encompasses the need of three to four different lateral tracks in the dredged channel during the same winter (Fig.6). This also depends on the actual traffic of the vessels during the next years.

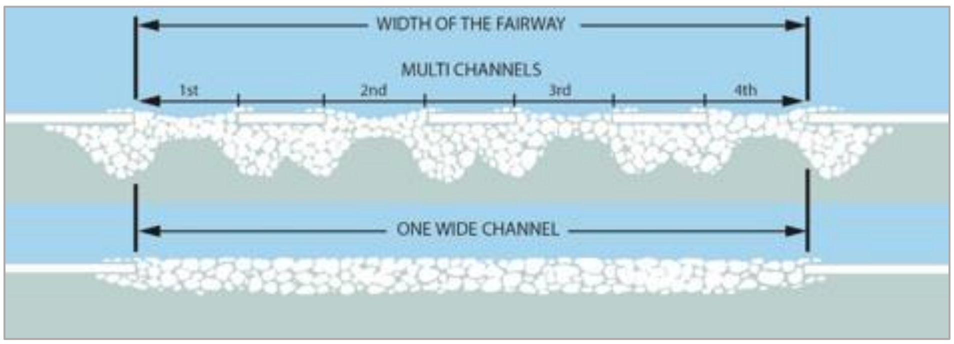

Figure 6: Multi-channels approach for the North Access channel to Sabetta

The access channel to the Port of Sabetta also needed to be dredged (Fig.7).

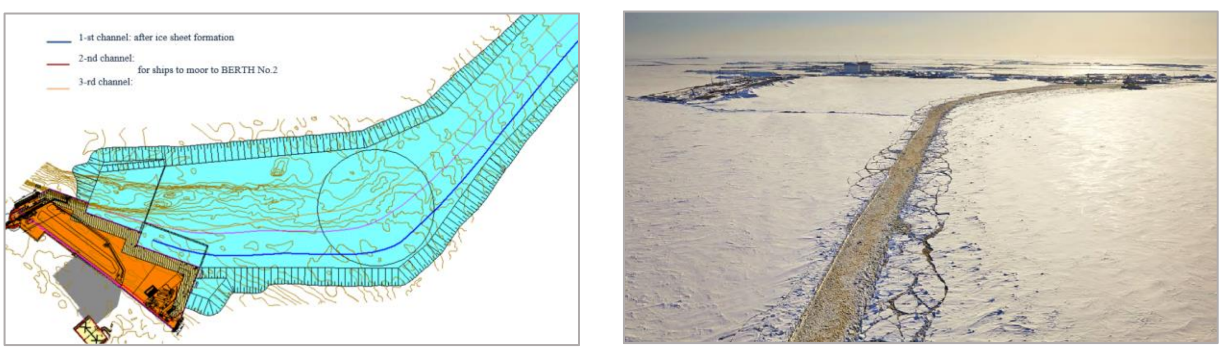

Figure 7: Access channel to the Port of Sabetta

3.2 The dredging works

An armada of dredging vessels have started the works in 2012 offshore Sabetta, in order to the construct the quays of the Marine Offloading Facilities (Fig.8).

Figure 8: Dredging works in access channel near MOF

3.3 The Sabetta Port lay-out

The review of existing ports in similar Arctic conditions (examples of Dudinka in Ienissei River and Vitino) has concluded that the export jetties of the future LNG Plant have to be protected from currents and drifting ice in order to be operational year-round.

One design requirement is to have a water depth of 15m to ensure safe access and maneuverability of large vessels in the Port. The 15m isobath is located about 7,5km from the shoreline near Sabetta. The compromise between long marine structure and limited dredging versus jetties close to shore with significant dredging , led to an optimized option of marine infrastructures located close to the shore with two ice protection barriers, one at the Northern side (about 1,850m long), the other at the Southern side (about 2,000m long). The turning basin is located inside the Port and the two export jetties are built laterally to the southern breakwater: the entrance width of the Port is about 500m and the access channel requires a length of about 5km to be dredged (Fig.9).

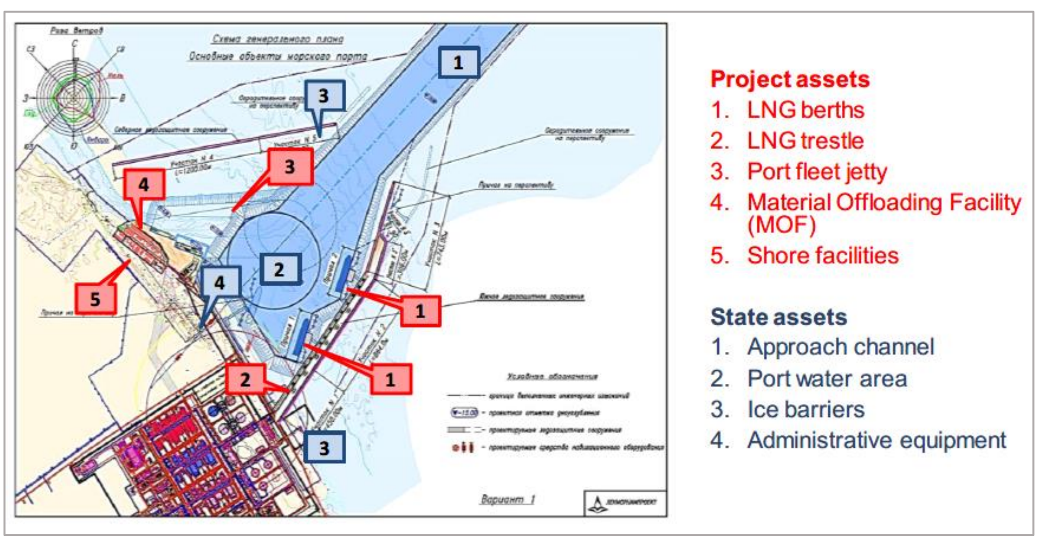

Figure 9: The general lay-out of the Arctic Port

The development of the Sabetta Port started with a first stage: the dredging works offshore of the future MOF (Fig.10) in order to build the four quays for unloading the multipurpose vessels and module carriers and accommodate the future Port support fleet (4 tugboats and one port ice-breaker).

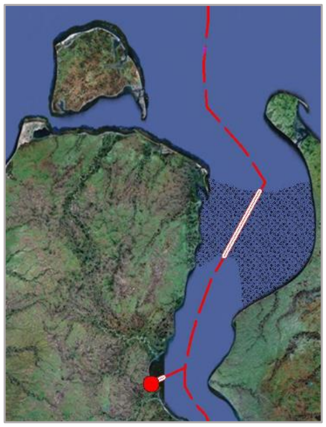

Figure 10: North Channel (left) and Construction of Marine Offloading Facilities

In a second stage, the main jetties for exporting LNG and condensates had to be built at the same time as the storage tanks and Liquefaction Plant : Jetty 1 for LNG and Jetty 2 for both LNG and gas condensates (Fig.11). The main jetties are protected by breakwater and ice protection barriers in order to allow the loading operation of the ships all year round, unexposed to the river currents and drifting ice blocks during the break-up period.

Figure 11: Construction of the South-West Breakwater and Ice Barrier & Main Export Jetties 1 & 2

3.5 The ice management in the Sabetta Port

A lot of experience has been accumulated since the first year of multipurpose ships calling at Sabetta during winter season, in particular for the ice management. The use of tugboats and ice-breakers ahead of the arrival of the ships as in other subarctic ports has been the primary tool to make the quays of the Marine Offloading Facilities ice-free and accessible.

Figure 12: Ice management by ice-breaker during MOF construction

However, some of the corners and extremities of the quays were still clogged with ice and difficult to reach by the support vessels without the risk of hurting the quays and deteriorating the fenders (Fig.13). This could jeopardize the delivery schedule of the module carriers.

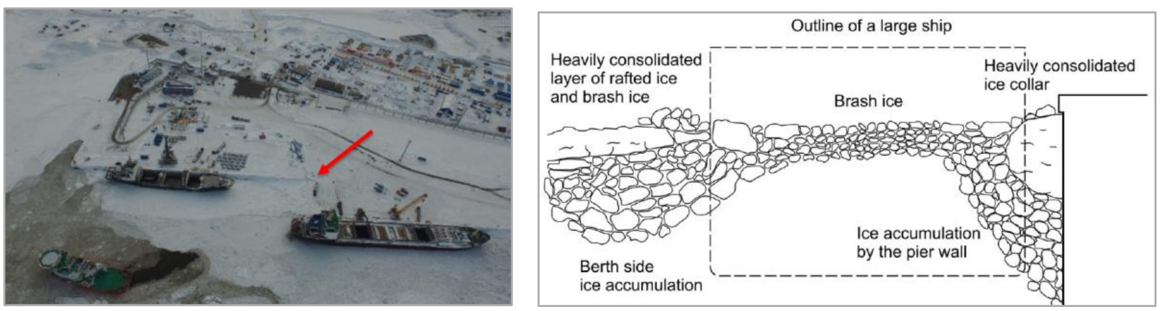

Figure 13: Ice accretion on MOF quays

An additional brash ice management equipment was tested to mitigate this issue.

A pilot mobile brash ice management system (BIMS) was installed at one quay of the MOF for assessing the efficiency of such system and size a potential global system for the area of main jetties of the Port (Fig.14).

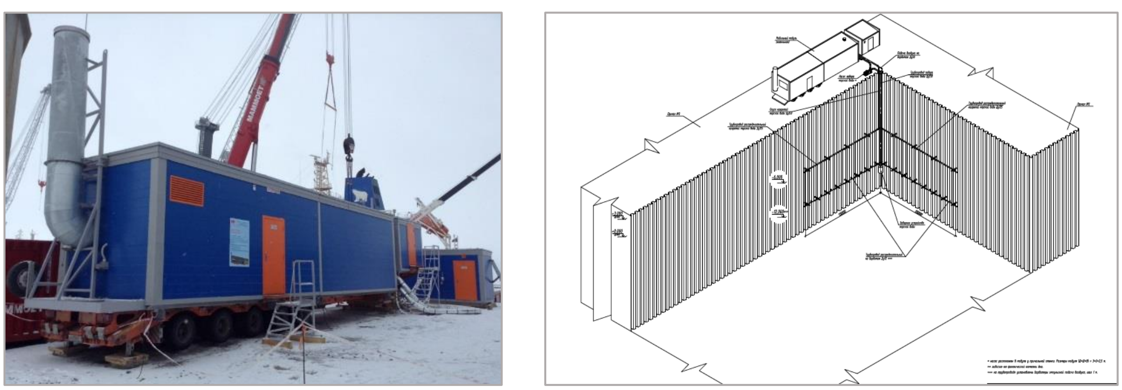

Figure 14: Pilot mobile BIMS

The project team has visited quite a lot of ice infested ports in Finland to witness the mitigation measures used to keep the accessibility of ships during winter seasons (e.g. Vuosaari). Some have adopted a brash ice management system using recovered energy from nearby power plant to heat the water of some part of the Port and slow down the growth of brash ice. A system of compressed air generating bubbles and helping to diffuse the heat is implemented (Fig.15).

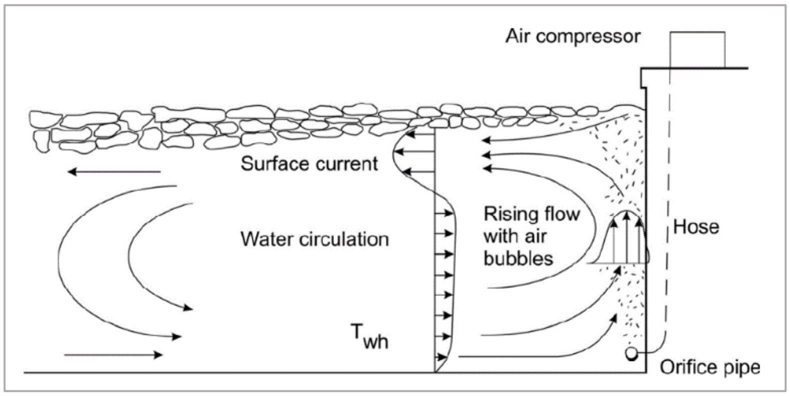

Figure 15: BIMS principle with warm water and bubbles

However, this system has not yet been implemented for a port as large as the Sabetta one.

Assuming the final layout of the Port, the local ice conditions and the anticipated maritime traffic in the Sabetta Port, a campaign of simulations has been run in order to size the equipment and assess the impact of such BIMS (Fig.16).

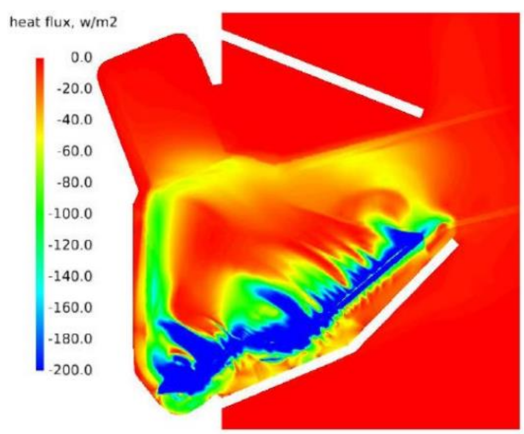

Figure 16: Simulation of heat diffusion of a BIMS inside the Port

However, as the ice management needs an integrated solution encompassing the operations of ice breakers and tugboats, as well as the actual contribution of maritime traffic and the maneuvering tactics, the heat provided by the ballast system of the vessels, and the supplement to be provided by the BIMS, the final design of the equipment and its installation has not yet been decided at the time of the first train commissioning.

3.6 The Sabetta Port support fleet

For the starting of the commercial operations of the LNG Plant, a dedicated support fleet was defined, consisting of 4 tugboats with reinforced hull and fire-fighting capabilities, able to handle the large vessels and assist the ice management, and a Port icebreaker.

	Ship	Propulsion Power, mW	Ice class
1.	Port Icebreaker"ARC - 124"	12	Icebreaker - 7
2.	Icebreacking tug "T 40105"	7	Arc - 6
3.	Escort tug "T3150A" - "Пур"	4	Arc - 4 (Hull 5)
4.	Escort tug "T3150A" - "Тамбей"	4	Arc - 4 (Hull 5)
5.	Icebreacking tug "T 3687 "	6,4	Arc - 6

Figure 17: Dedicated Support Fleet of Sabetta Port for the Project

4. THE MODULE LOGISTICS FOR THE LIQUEFACTION PLANT

One of the biggest challenges of this Arctic project has been the safe and reliable transportation and timely delivery of Plant modules; no piece of the puzzle could be missing. Indeed the modules have been built mostly in East Asia and delivered in a similar way as the future LNG export scheme.

About 152 large modules, representing about 360,000 metric tons with 55,000 tons of reinforcing and sea fastening), coming from 10 different yards in China or Philippines have been loaded on a fleet of 23 heavy lift vessels and modules carriers. Two dedicated Arc7 module carriers have been specially built in China during the first years of the project to allow an enlarged window of deliveries on site in winter conditions. A special Fleet Operations Center has been set to monitor the routing of the vessels with regard to the ice conditions, providing the data for decision and route changing should any risk be identified during a voyage: whether to follow the route through the Western route (Suez Canal) or be ready to enter the Eastern route (Bering Strait) (Fig.18). 77 shipments of large modules have been organized, with a total of 22 voyages through the Bering Strait.

Figure 18: The module carriers fleet routing from Asian yards to delivery at Sabetta

A MISY (Module Intermediate Storage Yard) had been open in the Zeebrugge Port (Belgium) in order to serve as a buffer for the modules before final transfer to the site, especially in winter season (Fig. 19 & 20).

Figure 19: Plant Module leaving the MISY of Zeebrugge towards Sabetta

Figure 20: Module unloaded at Sabetta on a SPMT (Self-Propelled Modular Transporter)

5. THE DESIGN OF THE LNG CARRIERS AND CONDENSATE TANKERS FLEET

From the initial studies for the shipping scheme, the ships designed for the export of the production of the LNG Liquefaction Plant should be large enough for economies of scale and able to be independent from the continuous assistance of ice-breakers during their voyages along the Northern Sea Route. Their large size and width would have required two ice-breakers to open a track in the ice.

After extensive studies of existing options of vessels in service in Arctic regions and innovative solutions, the technical specifications of the first Ice-breaking LNG Carrier were finalized : a Double-Acting System type ship (Fig.21), capable of sailing both ahead and astern, having an optimised open water ice-breaking bow for both open water and light ice condition and an optimised ice-breaking stern when the ice conditions are more severe.

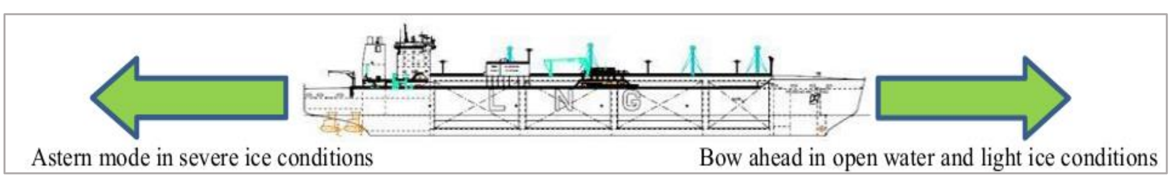

Figure 21: Double-Acting System ship

An optimized hull form and innovative and powerful propulsion plant consisting of three azimuthal thrusters of 15 MW each will allow to break the ice and maneuver in the icy waters. A reinforced hull with an Arc7 ice class notation, and double hull structure will ensure adequate safety to the cargo containment system of the ship. The boil-off gas of the LNG inside the cargo tanks will be used for the feeding of the Dual Fuel Diesel engines (6 units) for powering the hotel load, the propulsion and all cargo handling operations. The winterization of the ship will allow operations at very low ambient temperatures, down to -52°C (Fig.22).

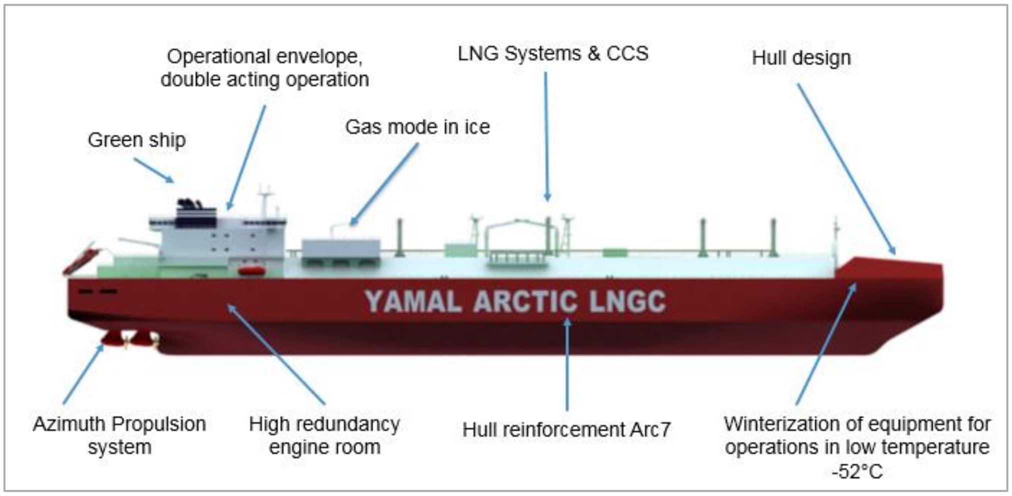

Figure 22: The Arc7 ice-breaking LNG carrier

Fifteen of such Arc7 LNG Carriers have been ordered to a Korean shipyard (DSME) and the first ones have already been delivered at the end of year 2017 and deployed to service the production of the first Train of Yamal LNG. The first one, named "*SCF Christophe de Margerie*" (Fig. 23) has successfully carried out a full campaign of ice trials in the Arctic, in March-April 2017, demonstrating higher performances and ice-capabilities than expected: the ship is capable of sailing at more than the expected figures of 2,0 knots ahead and more than 5,0 knots astern in 1.5 m thick level ice, and has better maneuvering capabilities than estimated.

Figure 23: The SCF Christophe de Margerie, first Ice-breaking LNG carrier of the Yamal trade Fleet
Courtesy of DSME

With the same assumption for the design, two Arc7 Condensate Tankers are being built for the project, one in Finland, one in China to start the export in 2018.

6. THE TRANS-SHIPMENT TERMINALS IN EUROPE

As part of the transportation scheme, some potential trans-shipment terminals in Europe have been assessed during the phase of construction of the Arc7 LNG Carriers. The project has a long term agreement with the Terminal of Zeebrugge, where an additional storage tank has been erected and some dedicated equipment fitted. The trans-shipment can be from ship to ship through the jetty or from the ship to storage to ship.

Other alternate trans-shipment terminals can be also used, such as Dunkirk LNG (Fig.24), Montoir de Bretagne (France) (Fig. 25), or Gate LNG (Netherlands), as the LNG Carriers are compatible with them.

Figure 24: Trans-shipment at Dunkirk LNG
Courtesy of Dunkirk LNG

Figure 25: Trans-shipment at Montoir de Bretagne between an Ice-breaking LNG Carrier and a conventional LNG Carrier
Courtesy of Nantes Saint Nazaire port

7. CONCLUSIONS

Accordingly, a lot of challenges have been addressed in order to launch the Yamal LNG Project.

All the lessons learnt during the various phases of design, construction, and commissioning of the Plant will provide solid foundations for future projects and serve as a reference for others who want to develop and exploit the large gas reserves of the Arctic area.

Figure 26: View of the Yamal Project in Sabetta

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