Analysis of Russian Arctic LNG projects and their development prospects

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Abstract. This article provides a detailed description of the Yamal LNG project, including a general description of the project, supply geography, project infrastructure including port, airport and settlement of Sabetta as well as resource base of the project and LNG transportation routes. Opportunity of the new North-South transport corridor for LNG transportation is considered. The issues of gasification of the Arctic zone of Russia using LNG were also studied including LNG transportation facilities, shore storage systems, floating gas storage and floating power plants. Strategic analysis of Russian Arctic LNG projects was carried out. Conclusions have been made on the localization of production of critical equipment for LNG production as well as the opportunities of export of Russian gas liquefaction technology to world markets. Also the localization of shipbuilding for the needs of Arctic LNG projects, the diversification of LNG sales routes, the use of LNG as a transport fuel and the gasification of a number of Russian regions using the LNG logistics infrastructure were offered.

1. Introduction

The global LNG market continues to grow reaching a volume of 316.5 million tons in 2018. The 12% market growth was primarily due to the introduction of new production facilities in Australia and the USA. Most long-term forecasts indicate that LNG demand will continue to grow due to a cumulative increase in gas demand as one of the most affordable and greenest energy sources. In the next five years LNG trade may increase by 30%. It is also worth noting that the share of LNG in the overall global structure of gas consumption will most likely to grow. It is also expected that in the next 15 years the share of gas in the global energy balance will increase to 26%.

By 2035 global demand for LNG will double and amount to about 600 million tons. The Asia-Pacific region will become the main locomotive of the increase. China and India together will cover more than 50% of the growth in demand for LNG in the Asia-Pacific region. As a result the share of LNG in world trade will grow from today's 35% of the total gas trade to 51% by 2035.

Russia occupies the leading role in the global gas market both in reserves and in gas production and export through the pipeline system. At the same time, according to the Ministry of Energy of Russia, in 2017 LNG exports from Russia amounted to 11.7 million tons (16 billion cubic meters), which is
about 4% of the global indicator, while the share of LNG in the total export of natural gas from Russia amounted to 6.5%.

In the next 15 years, subject to the launch of new Russian LNG projects, it will be possible to increase Russia's share in global LNG production to 20% [1].

Until 2017 in Russia despite the enormous resource base there was only one LNG plant operating — the Prigorodnoye production complex, operating under the Sakhalin-2 project, consisting of two production lines with a design capacity of 9.6 million tons per year. The actual production of the plant exceeds the declared one - in 2017, 11.49 million tons of LNG were produced. Initially the project was implemented exclusively by foreign companies Shell, Mitsui and Mitsubishi. Gazprom did not become a shareholder in the project until 2007, when the plant was actively built, and gas export contracts were contracted by more than 70%.

Yamal LNG was the first LNG production project, the controlling interest in which was originally owned by Russian shareholders. December 08, 2017 Yamal LNG plant shipped the first batch of liquefied natural gas (LNG) with a volume of 170 thousand cubic meters. Yamal LNG consists of four production lines with a planned capacity of 17.4 million tons of LNG per year, of which three lines with a capacity of 16.5 million tons per year are currently commissioned. Total in Russia in 2019 will be produced about - 29 million tons of LNG, or about 9-10% of global production [2].

In the next 7 years, Russia plans to significantly increase its capacity for large-scale production of liquefied natural gas (LNG). Until 2025, three more projects will be launched. The Arctic LNG-2 projects, the third line of the Sakhalin-2 plant, and Baltic LNG are planned for construction. The total capacity of all LNG projects will be 41.2 million tons. In general, this will increase the share of Russian LNG in the market to 15% by 2025. In the far horizon, with the emergence of additional demand for LNG, the implementation of the currently frozen Pecher LNG project and Arctic LNG-3 projects is possible, and the Shtokman LNG project can also be resumed. The total capacity of these LNG projects may amount to 49 million tons [3].

The study focuses on the analysis of Arctic projects for large-scale LNG production. The purpose of this study is to formulate proposals aimed at the development of Arctic LNG projects.

To achieve this goal, the following tasks were solved: the characteristics of existing and prospective Arctic LNG projects “Yamal LNG”, “Arctic LNG-2” were given, the scope of logistics of “Yamal LNG” was given, the strategic analysis of the projects was carried out, opportunities for gasification of social and economic infrastructure facilities were formulated, as well as key risks were identified and proposals for the development of Arctic LNG projects formulated.

2. Materials and methods

All information base of research is gathered from open sources.

For the analysis of LNG projects materials and reports of the PAO Novatek, PAO Gazprom, Skolkovo Energy centre, International Gas Union, World Wide Fund (WWF), JSC PricewaterhouseCoopers Audit, Ernst & Young LLC were used.

For the analysis of decisions and resolutions of the government of the Russian Federation materials of meetings of the Government of the Russian Federation, the orders of the Government of the Russian Federation, materials of meetings with participation of the Russian President and the strategy of development of the ship-building industry until 2035 were used.

Current LNG project information was analyzed on the basis of publications of the newspapers — Kommersant and Vedomosti.

The expert assessment method and strategic analysis of strength, weaknesses, opportunities and threats of Russian arctic LNG projects were used in this research.

3. Results

3.1. Characteristics of the Yamal LNG project

3.1.1. General characteristics of the project. Yamal LNG is a key project of PJSC NOVATEK for the production of liquefied natural gas with a design capacity of 17.4 million tons of LNG per year. The
project operator and owner of all assets is OJSC Yamal LNG. Together with PJSC NOVATEK with a 50.1% ownership interest, the Yamal LNG project shareholders are French oil and gas company Total — 20%, China National Petroleum Corporation CNPC — 20%, and the Chinese investment Silk Road Fund — 9.9%.

In order to minimize the volume of construction and installation work on the site due to difficult climatic conditions, a modular approach to the construction of the LNG plant was chosen. The three main lines of the plant consist of 142 large-sized modules weighing from 85 to 6400 tons, which were manufactured at the shipyards of the contractors. One of the features of the project is that the plant is built on permafrost.

The first three production lines of the Yamal LNG plant use C3MR natural gas liquefaction technology, mainly based on heat removal by an external refrigerant. Initially, the C3MR process (GB 1291467 A, 10/04/1972) was developed by Air Products for the LNG plant in Brunei. The first LNG production line with a design capacity of 5.5 million tons was launched in December 2017. The first batch of LNG was loaded on December 8, 2017 at the port of Sabetta on the Christoph de Margerie LNG tanker, the world's first Arc7 ice-class gas carrier. The first LNG on the second production line was received in July 2018. Currently, the line operates at a design capacity of 5.5 million tons of LNG per year. The third LNG production line, also with a capacity of 5.5 million tons of LNG per year, was launched in November 2018 at Yamal LNG, ahead of the original schedule by more than a year.

The fourth production line of the Yamal LNG plant with a capacity of up to 0.9 million tons of LNG per year is planned to be launched in 2019.

In February 2018 Rospatent released information on the confirmation of the patent of NOVATEK PJSC under RU No. 2645185 C1 for the Arctic Cascade natural gas liquefaction technology. The liquefaction process consists of two stages, which ensure high energy efficiency of the technology due to the maximum use of the Arctic climate. In the proposed Arctic Cascade technology, in the first liquefaction circuit, pure ethane refrigerant is used instead of mixed refrigerant. This solution greatly simplifies the liquefaction process, allows the use of simple evaporators instead of complex multi-threaded heat exchangers for mixed refrigerant, and expands the list of plants capable of manufacturing the necessary equipment. Subcooling with nitrogen (the second stage of cooling) allows the use of heat exchangers on single-phase environments. Liquefaction at high pressure of the feed gas ensures the compactness of the main technological equipment, which will reduce metal consumption.

Calculations show that the energy costs of LNG production using the new NOVATEK technology are about 220 kW per 1 ton of LNG. This is 20% less energy when using the American C3MR technology. The first NOVATEK patented gas liquefaction technology is designed to use equipment from Russian manufacturers. This technology is used in the fourth production line of the Yamal LNG plant, and it is also planned to use for the Arctic LNG-2 project [4].

3.1.2. LNG Supply Geography. Already by the March 2016 under long-term Yamal LNG agreements with customers 96% of liquefied gas was contracted, which will be produced at the plant for 20-25 years. Approximately 86% of LNG supplies will go to the Asia-Pacific region.

Novatek, through its subsidiary trading units Novatek Gas & Power, registered in Switzerland and Novatek Gas & Power Asia Pte. Ltd., registered in Singapore, sells LNG to customers under long-term and short-term contracts. In particular, LNG shipments were shipped to the markets of Spain, India, China, Brazil, etc.

The shareholders of the Novatek project - Total and CNPC - will purchase 2.38 million tons, 4 million tons and 3 million tons per year, respectively, from Yamal LNG on a long-term basis. The structure of Gazprom - Gazprom Marketing & Trading Singapore (GM&T) entered into a contract for the supply of up to 2.9 million tons of LNG per year. Another 2.5 million tons was contracted by the Spanish Gas Natural Fenosa. Novatek’s trading subsidiary, Novatek Gas & Power, has agreed to sell 1 million tons of LNG to the French Engie, 0.9 million tons to the British Shell International Trading Middle East and 0.5 million tons to the Gunvor trader.
3.1.3. **Yamal LNG Project infrastructure.** The project infrastructure includes the Sabetta international airport, the Sabetta seaport, roads, power lines, inland transport pipelines and workers camp.

*Port Sabetta.* Sabetta port is an arctic sea port on the western shore of the Gulf of Ob of the Kara Sea in the Yamal region of the Yamal-Nenets Autonomous Okrug of the Tyumen Region. The port is located on the eastern coast of the Yamal Peninsula near the settlement of the same name Sabetta. The main task of the port is the transportation (mainly for export) of LNG, as well as ensuring year-round navigation on the Northern Sea Route.

The multifunctional port of Sabetta was built as part of the Yamal LNG Project on the principles of public-private partnership.

Federal property (the construction customer — Federal State Unitary Enterprise “Rosmorport”) includes ice-protective structures, an operational water area, access channels, ship traffic control and navigation support systems, and marine services buildings. Yamal LNG facilities include technological berths for the transshipment of liquefied natural gas and gas condensate, rolling cargo berths, construction cargo berths, port fleet berths, warehouses, administrative areas, engineering networks and communications.

As part of the construction of the Sabetta seaport facilities are built:

- approach channel 6 km long, 495 m wide, bottom mark minus 15.1 m;
- sea channel 49 km long, 295 m wide, bottom mark minus 15.1 m;
- port water area with a bottom mark of minus 15.2 m.

Currently, the port has 8 berths with a total length of 2007 meters. The direct infrastructure for LNG shipment for export consists of a shipping pier with two berths.

*Sabetta airport.* Sabetta airport is an international airport of federal significance. The operator of the airport is Sabetta International Airport LLC. The airport is a strategic object for the implementation of the large-scale Yamal-LNG project.

The airport passenger traffic in 2015 amounted to 127.7 thousand passengers, in 2016 - 237.7 thousand, in 2017 - 369.8 thousand. There are regular flights from the airport to Moscow (Domodedovo), Novy Urengoy, Salekhard, Samara, Tyumen, Ufa.

The airport is capable of receiving IL-76 aircraft, A-320, Boeing-737, Boeing 767-200, Sukhoi Superjet 100 aircraft and all lighter ones, as well as all types of helicopters. In 2017, the largest serial cargo plane in the world, An-124 Ruslan, landed at Sabetta Airport.

The airport complex includes an aerodrome that meets the requirements of ICAO Category I, a runway of 2,704 × 46 m in size, a hangar for aircraft, an airport terminal with a capacity of 200 passengers per hour, including the international sector for 50 passengers per hour.

*Settlement of Sabetta.* The settlement of Sabetta, located on the eastern coast of the Yamal Peninsula, is the base for the Yamal LNG Project. In the 1980s of the 20th century, the Tambey expedition of oil and gas exploration drilling was located in Sabetta. During the implementation of the Yamal LNG project, a modern infrastructure was built in the settlement for builders to live, auxiliary facilities for the life support complex were built: fuel and oil storage warehouse, boiler room, canteens, first-aid post, bathhouse, sports complex, administrative and household complex, hotel, sewage and water treatment facilities, warehouses food storage. Additional dining room, laundry, fire station, warm parking for cars, additional housing are being built. The peak number of employees at the construction stage of the Project was more than 30 thousand people.

3.1.4. **The resource base of the Yamal LNG Project.** The resource base for the project is the South Tambeyskoye field located in the northeast of the Yamal Peninsula.

The South Tambeyskoye field, discovered in 1974, consists of 42 gas-saturated formations with depths ranging from 900 to 3730 m and complicated by three domes. The field includes 112 Valanginian gas condensate deposits, 10 Jurassic gas condensate deposits, as well as two Cenomanian deposits characterized by dry gas. Productive formations have a wide range of permeability and hydrostatic distribution of reservoir pressure. The development of the field is planned using horizontal wells with a bore depth of up to 5000 m and a horizontal portion of the bore of up to 1500 m. The
exploration and production license for the South Tambeyskoye field is owned by Yamal LNG OJSC and is valid until 2045.

As of December 31, 2017, the field contained 683 billion cubic meters of proven reserves of natural gas and 21 million tons of proven reserves of liquid hydrocarbons according to SEC standards [5].

3.1.5. Yamal LNG project current transportation routes. The unique location of the Yamal Peninsula makes it possible to create a flexible competitive logistics model that ensures year-round supply of LNG to the markets of the Asia-Pacific region and Europe. The planned LNG production volume is almost completely contracted and will be delivered mainly to Asian markets. LNG will be delivered to the markets of Northeast Asia in the summer through the Northern Sea Route, and in the winter through the western route with LNG transshipment at one of the European regasification terminals.

For the Yamal LNG Project, special ARC7 ice-class tankers (according to the Russian classification) designed and built for year-round navigation without icebreaking support in the western direction and during the summer navigation in the eastern direction along the Northern direction were designed and built for the Yamal LNG Project (currently built 10 out of 15 ships) [6].

3.2. Opportunity of the new North-South transport corridor for LNG transportation. The project "Ob Irtysh".

3.2.1. General characteristics of the North-South transport corridor. Following the gradual expansion of the development strategy of the Russian Arctic, the Ob - Irtysh route is becoming increasingly important for the integration of the Eurasian continent. Due to the special geographical position, the Irtysh-Ob river route will allow connecting Central Asia and the Arctic regions, by river, road, pipeline, railway transport and other means of communication to unite the regions of Asia and the North West of Siberia. The North-South corridor implies the creation of a logistics chain for the movement of tank containers with LNG from production complexes on the Yamal Peninsula and the Gydan Peninsula along the Ob - Irtysh water system to consumers in China.

The waterway from the source of the Irtysh in China to the mouth of the Ob in the Kara Sea is 5410 km and is navigable throughout the route to the border with China while the Ob part of the route (about 1200 km.) naturally provides depths sufficient for river-sea navigation. Management of this route on Russian territory is carried out by the FSBU “Administration of the Ob-Irtysh Basin of Inland Waterways” (controlled by the Federal Agency for Sea and River Transport). Currently more than 1,500 people and 192 specialized vessels provide navigation. About 6 million tons of cargo and 1 million people are transported annually. The route is equipped with control and correction stations to accurately determine the position of the vessel.

Considering that a significant part of the route (1700 km, part of the Irtysh River) passes through Kazakhstan, its role in ensuring the navigability of the route is important. In particular, there are three large reservoirs (Bukhtarminskoye, Ust-Kamenogorskoje and Shulbinskoye) and Lake Zaysan, which can be effectively used to regulate the water level of the river and, as a consequence, its navigation, on the Kazakhstan Irtysh River.

The source of the Irtysh River, called Black Irtysh, is located in China and although it has no practical shipping value, however, the Chinese side has the ability to regulate its flow and, accordingly, influence the navigability of the route in Kazakhstan and the Russian Federation. That is why it is important to sign a trilateral agreement on the use of Irtysh waters, which China has not yet made. The existing bilateral agreements on the rational use and protection of transboundary rivers concluded by Beijing with Astana and Moscow in 2001 and in 2008, respectively, do not meet the interests of organizing commercial shipping at the final stage of the route and do not stop the China from withdrawing excessive water from the river. Black Irtysh unilaterally, which has a negative impact on the navigability of the waterway in Kazakhstan and the border regions of the Russian Federation (to the city of Omsk).

Thus, the waterway "NSR - river Ob - river Irtysh" has great potential in organizing transportation from Europe, East and Southeast Asia to the countries of Central Asia, especially those cargoes that are not possible or economically inefficient to transport by rail and road. In addition, this route
provides a convenient alternative route for the delivery of hydrocarbon resources from the Arctic region to the China, the Central Asia countries and India. Against this background, the Ob and Irtysh rivers can become a link between the NSR and the Silk Road and combine these transport corridors into a single transport system.

However, to implement this initiative, it is necessary to organize trilateral cooperation between China, Kazakhstan and Russia, aimed at creating the appropriate infrastructure and maintaining the waterway in a navigable condition. In addition to the construction of transshipment port facilities in the Gulf of Ob, which is already being successfully implemented by the Russian Federation, it is also necessary to create a continuous cascade of backed up basins (reservoirs) on the Irtysh River, which will provide at least 5 m depth along the entire route during the navigation period. The scheme for the integrated use of the Irtysh River developed by the Leningrad branch of Hydroenergoproekt in the 1950s, adjusted to modern realities.

To implement these plans, a trilateral agreement should be concluded, based on the following main ideas:

- The participating countries undertake efforts to ensure the transit depth along the Irtysh-Ob highway, presumably 3-5 m. For this, the construction of additional hydraulic structures is necessary, and technical and financial cooperation of the participating countries must be agreed upon.
- The parties undertake to transfer the water of the Black Irtysh, Irtysh, Ishim, and Tobol rivers through the border sections in a certain quantity and at a certain time.
- The shipowners of the parties receive the preemptive right to use the Irtysh-Ob deep-sea trunk and all the associated inland waterways of the participating countries, subject to all the rules for navigation on them.

These events will create an uninterrupted deep-sea route from the Arctic Ocean to China and provide the possibility of direct non-reloading water transport between Russian Arctic LNG projects and China. The implementation of the North-South transport corridor is possible with the help of the capacities of the Ob-Irtysh River Shipping Company and the Irtysh River Shipping Company [6].

3.2.2. JSC Ob-Irtysh River Shipping Company. Ob-Irtysh River Shipping Company JSC (OIRP JSC) is one of the largest water transport enterprises in Western and Eastern Siberia and the only one in the Ural Federal District.

JSC "OIRP" was formed by a resolution of the Council of Ministers of the RSFSR in 1982. The need to create an enterprise was caused by the active development of the oil and gas fields of the Tyumen region and, as a result, the increasing volume of cargo transportation. Vessels delivered oil produced in the fields of the region by tankers and oil barges to the Omsk oil refinery, and construction cargoes for the construction of oil and gas pipelines to the north of the region.

Currently, the geography of the company extends from Yamal to the Caspian. The fleet of OIRP JSC can transport general cargo from the berths of Arkhangelsk, Severodvinsk, ports on the Ob River to the settlements Kharasavey, Bovanenkovo, Sabetta, as well as to the unequipped shores of the Yamal Peninsula. In recent years, JSC OIRP has been actively transporting goods to Sabetta, the next for the construction of Yamal LNG facilities.

Own self-propelled and non-self-propelled fleet totals more than 400 vessels. The shipping fleet has pushers of various designs (capacity from 300 hp to 2,400 hp), platform barges and ramp barges (with carrying capacities from 1,000 tons to 2,800 tons), including vessels of the mixed class “river-sea”.

The group of companies also includes river ports in Sergino, Salekhard, Surgut, Tyumen, Neftyugansk, Urengoy, Salekhard.

3.2.3. JSC Irtysh Shipping Company. The Irtysh Shipping Company, which has a fleet for transporting oil and oil products, with a total capacity of more than 100 thousand tons, including tankers capable of transporting various types of oil cargoes to coastal areas, inaccessible due to the shallow depths for large sea vessels on such destinations like: West coast of the Yamal Peninsula (Kharasavey), estuaries of the Yenisei, Dudinka, Igarka, Bely, Velkitsky, Dikson and others.
3.3. Characteristics of the Arctic LNG-2 project

The LNG plant project consists of three phases with a total capacity of up to 18 million tons. The Utrenye Field with proven reserves of 388.5 billion cubic meters will be the resource base (according to the SEC classification as of December 31, 2016) and located on the neighboring Gydan Peninsula with Yamal. The license for it is owned by the Novatek's subsidiary Arctic LNG-2.

3.3.1. Technical Aspects of the Project. Unlike the Yamal LNG project, gas liquefaction lines will be located not on the coast, but in the Kara Sea on the basis of gravity type (OGT) and the rest of the equipment will be produced at the Kola shipyard in the Murmansk region.

Each LNG production line will have a capacity of about 6.6 million tons per year and the following parameters: OGT dimensions - 300 x 152 m; OGT mass - 440,000 tons; mass of the upper buildings - 120,000 tons; capacity of LNG tanks - 229,000 m³; the capacity of the condensate reservoirs is 75000 m³; OGT includes LNG and condensate tanks, storage tanks for liquids of engineering systems, pumps and specific systems (mooring system, ballast system, etc.).

A license for gas liquefaction technology has already been acquired from the German Linde AG - this was announced in May 2017. In order to implement the project, Linde AG signed a strategic cooperation agreement with Novatek, which was also joined by the French Technip and Research and Design Gas Processing Institute (NIPIGAZ). At the same time, the fourth Arctic Yamal LNG production line implements the Russian Arctic Cascade gas liquefaction technology. Perhaps, if successful, this technology will be applied to the Arctic LNG 2 project, taking into account the increase in tonnage of LNG production.

3.3.2. Potential members and lenders. The project may have the same membership as Yamal LNG. The interest in the Arctic LNG-2 from the Chinese CNPC in August 2016 was reported by the head of its external relations department Li Yueqiang. In St. Petersburg, on May 24, 2018, as part of the XXII St. Petersburg International Economic Forum, Novatek and Total signed a binding a greement on the conditions for joining the Arctic LNG 2 project. The agreement provides for the acquisition by Total of a 10% stake in the Arctic LNG 2 project, as well as the right to acquire up to 5% additionally when NOVATEK takes a decision to reduce its share in the project below the planned 60%. In general, Novatek plans to retain a 60% ownership interest. The project cost is determined in an amount equivalent to $ 25.5 billion.

3.3.3. Project Risks. One of the project's risks is growing competition in the global LNG market, under the influence of which it will be difficult to contract gas from Arctic LNG-2. The production of liquefied natural gas at the second Novatek plant is due to begin in 2022: according to the International Energy Agency, by this time global LNG production will grow to 650 billion cubic meters per year, compared with 452 billion in 2016, while demand will reach only 460 billion. In this context consumers will have more opportunities to get low prices.

Also difficulties in attracting external financing cannot be ruled out: as in the case of Yamal LNG, project participants will have to rely primarily on funds from Asian banks.

3.4. Gasification possibilities of the Russian Arctic zone using LNG

There is currently no LNG infrastructure in the Russian Arctic zone. Nevertheless, its individual elements are created by Novatek, primarily in the course of the implementation of its Yamal-LNG project. These include the port infrastructure of Sabetta, the construction of a fleet of gas carriers, as well as plans to use icebreakers on LNG for port pilotage in Sabetta.

LNG consumers in the Arctic zone can be — heat and power generation facilities, gasification of settlements, industrial projects, vehicles using gas as a motor fuel.

The use of LNG is associated with the following customers located in close proximity to the LNG production or storage system and in river waters and in areas with transport accessibility.

The main consumers of LNG in the Russian Arctic may be:
coastal and island territories including: ports of Murmansk, Vitino, Kandalaksha, Onega, Arkhangelsk, Mezen, Naryan-Mar, Amdemra, Varandey, Dikson, Dudinka, Khatanga, Tiksi, Providence, Cape Schmidt and Big Solovetsky Island.

- industrial facilities: The First Mining Company, the Taibass project, mining projects in Chukotka.

- objects along the inland waterways: the Ob, Yenisei, Lena, Northern Dvina rivers, and also the White Sea-Baltic Canal.

The LNG supply and use production chain consist of the LNG supply from the plant to a gas carrier or to cryogenic tank containers, LNG transportation to the consumer, discharge to a floating or ground gas reception and storage system.

Possible technical solutions for gasification of facilities of the Russian Arctic zone include following issues [7].

3.4.1. LNG transportation facilities. The supply of LNG by water can be carried out in tank containers and specialized gas carrier vessels. This requires opportunities for loading by a port crane or a bulk carrier crane a container from shore to ship or with large deliveries of LNG, loading a specialized gas carrier vessel from an onshore LNG storage and shipping complex.

The projects of small-tonnage gas carriers implemented by Russian companies provide for the construction of small vessels, primarily for bunkering. However, they can also be used to supply LNG to the consumer. The typical LNG transportation volume is 3,000–7,000 m³ LNG. The volume of up to 12 thousand m³ for gas transportation is widespread in the transportation of LNG.

3.4.2. Shore storage systems. Onshore storage systems can be of three types in geometric form, in which LNG is stored either under overpressure (1-2) or at atmospheric pressure (3) — 1 cylindrical C-type, which can be installed horizontally and vertically; — 2 spherical; — 3 with a flat bottom and an external concrete wall.

Gas storages can have LNG transfer functions to cryogenic tankers for supply to coastal consumers and bunkering of ships. Technological operations begin with a discharge to the LNG storage facility from a gas carrier vessel.

3.4.3. Floating gas storage. Floating gas storage facilities (FSU), incl. with regasifier on board (FSRU), are one of the most important factors in the development of the LNG market in the world. According to the results of October 2017, 24 units were operated, orders were placed for 15 units, and orders for new floating storage facilities in the next 5 years will amount to 30-50 units. The total capacity of floating stations reached 83 million tons per year. Typically, these plants are powerful and have the goal of providing energy to large consumers. Nevertheless, 3 small-tonnage floating storage facilities (Caribbean Sea and Indonesia) are already operating in the world and 5 units are under construction.

FSRUs operate in most cases in emerging markets that require fast LNG supplies until they develop their own production or renewable energy sources. FSRUs require much less time to accommodate than regasification capacities onshore (about 18 months for FSRU and about 5 years for onshore facilities).

The number of FSRUs will grow at a faster rate than ground-based capacities. They can be owned or leased by a person who wants to access LNG. It is believed that renting an FSRU significantly reduces the overall capital cost of the project.

3.4.4. Floating power plants. As far back as the 1960s, a project was developed in the USSR for the construction of the first floating gas turbine power plants (PLES) of the “Northern Lights” type. The “Northern Lights” PLES is a series of Soviet mobile thermal power plants of project 1527 installed on towed floating facilities to provide electric and thermal energy in the form of steam or hot water to industrial inaccessible areas of the north and east of the USSR. The developer of the PLES project was “KB Mashproekt”. In 1969, the first floating generating power station based on a gas turbine power plant consisting of two gas turbine generators was launched at the Tyumen Shipyard. At the Northern
Lights PLES 1, 2 and 3, two GTG-1 gas turbine engines of 10,000 kW were installed. At the Northern Lights PLES - 4, 5, 6, gas turbine engines of 12,000 kW were installed. Gas turbine units can run on liquid and gaseous fuels. In total, six Northern Lights type PESs were built. The last of them, the Northern Lights-6, was built in 1983.

Intended for power supply of the north-eastern industrial regions of the country, until the launch of the Wartsila DF dual-fuel floating power plant in the Dominican Republic in 2011, they were virtually the only dual-fuel floating power plants in the world.

PLES was a single-deck non-self-propelled floating power plant with a power plant build in at the bottom. PLES was delivered to the place of basing along waterways, which made it possible to ensure its quick connection to consumers. The ship was designed taking into account the conditions of the Northern Sea Route.

In 2011, Vypel Design Bureau presented projects of a universal floating gas turbine station with a capacity of 20 MW and a mobile hovercraft station. The floating power plant is focused on power supply to hard-to-reach areas of the North, Northeast and Far East of Russia. It can be based in protected sea bays, as well as in river basins.

3.5. Use of LNG as a motor fuel
Another important segment of demand that is not specific related to any particular country, is the use of LNG for marine bunkering. The main driver for the development of LNG as a fuel for maritime transport is emission limits in a number of areas - for example, the planned IMO emission limits can stimulate the growth of LNG demand for bunkering from the current 1.5 million tons to 30-80 million tons, depending on the level of oil and gas prices, as well as the stringency of environmental standards. Demand for LNG for bunkering is very sensitive to the speed of infrastructure development and the timing of the introduction of environmental standards.

Currently, the world already has many years (up to 10 years) of successful experience in the construction and operation of ferries, including large passenger, patrol vessels, supply vessels using LNG as fuel. There is a design and active construction of dry cargo vessels, tankers, cruise, dredging vessels, tugboats. In 2016, the world's first LNG icebreaker Polar Class 4 Icebreaker was built and launched in Finland. Novatek has ordered 15 Yamalmax-class LNG tankers at shipyards in South Korea that use LNG as the fuel for its propulsion system.

The interest in switching to LNG increased after the IMO in 2016 confirmed the earlier decision to introduce global restrictions on the sulfur content in marine fuel in 2020. Switching to LNG is one of the most effective ways to prepare for the expected additional restrictions on the content of sulfur and nitrogen oxides, black carbon (soot), and ect [8].

3.6. Strategic analysis of Russian Arctic LNG projects
The strengths of Arctic LNG projects include: high availability of resource base; exemptions from mineral extraction tax, income tax, property tax & export duties; low cost of gas production; the possibility of expanding production capacities (Arctic LNG-2); the existence of long-term contracts for existing facilities (almost the entire volume of production under long-term LNG supply agreements has been contracted); political support for Novatek projects by government authorities [9].

The weaknesses of Arctic LNG projects include: subject to US sanctions; lack of own technological base for large-capacity liquefaction (including technology, basic equipment, related equipment); severe climatic and weather conditions, difficult ice conditions in the Gulf of Ob and associated transport component with ice conditions; lack of highly skilled workforce [10].

The opportunities of Arctic LNG projects include: raising environmental standards and the forced transition of transport in a number of regions of the world to LNG; growing global demand for LNG; the ability to export natural gas liquefaction technologies; expansion of LNG exporters due to the possible admission of new companies to export LNG; implementation of a new transport corridor along the North-South axis; gasification using LNG from non-gasified regions of Russia; gasification of transport infrastructure facilities in the Russian Arctic; use of LNG as fuel for transport and power plants [11].
Risks of Arctic LNG projects include: strengthening the sanctions regime; dependence of Arctic LNG sales on offshore communications; a possible long-term decline in global demand; the possibility of a global excess of LNG production capacity; inability of Russian industrial to ensure the production of all equipment required for liquefaction; “washing out” the entire added cost of LNG production in Western jurisdictions due to significant tax and duty exemptions, selling of LNG through a number of foreign traders, ordering the entire technological chain and equipment from Western companies, ordering supply vessels from foreign contractors, etc [12].

4. Discussion
Based on the analysis of Russian Arctic LNG projects it is possible to formulate practical offers for the implementation of the following measures aimed at the development of Russian arctic LNG.

4.1. Localization of production of critical equipment for medium- and large-capacity LNG production in Russia
One of the key tasks facing companies implementing LNG projects in Russia is the creation of domestic technologies and equipment for medium and large-capacity LNG production in Russia. This is necessary due to the lack of proprietary technologies for gas liquefaction, the shortage of cost-effective resources and the lack of licensors in Russia who have their own liquefaction technology for large-scale LNG production.

Under the current and possible future sanctions against Novatek and Gazprom, it is necessary to ensure the technological independence of key equipment companies in LNG production. The President of the Russian Federation approved the list of instructions following the meeting on the development of LNG production projects held on December 8, 2017. The first item of this plan is the instruction to the Government of the Russian Federation to approve the plan (“road map”) for the implementation of priority measures to localize critical equipment for medium and large-capacity production liquefied natural gas (hereinafter - LNG) and the construction of LNG carriers transporting LNG, paying particular attention to:

- to determine the list of critical technologies for the production, transportation, storage and use of LNG;
- on the formation and approval of a plan of research and development work on the creation of technologies for the production, transportation, storage and use of LNG, including the determination of the necessary funding for such work;
- to determine the list of production sites for the creation of equipment for the production, transportation, storage and use of LNG, including enterprises of the military-industrial complex implementing product diversification programs;
- to coordinate work on concluding agreements of intent between the public joint-stock companies Rosneft Oil Company, Gazprom, NOVATEK and these production sites, which include placing orders for the creation of equipment for the production, transportation, storage and use of LNG.

The localization of technologies and equipment for LNG production is the key to the success of the development of the Russian LNG industry in the context of widespread use by geopolitical competitors of the mechanisms of economic and political deterrence of the expansion of production and export of Russian natural gas. In this context, it is also worth considering the need to use Russian secure software platforms, components of automated process control systems, operating systems and software at LNG facilities in order to ensure the security of information and telecommunication systems of these facilities [12].

4.2. Export of Russian gas liquefaction technology to world markets
The development of Russian technologies and equipment for gas liquefaction requires significant capital expenditures, which, apparently, can only partially pay off when implementing projects on Russian LNG. In the case of the creation of the Russian “package solution” for the LNG production line, which includes the proprietary liquefaction technology itself, the main manufactured equipment, including cryogenic heat exchangers, related equipment (compressors, pumps, gas turbines), the
necessary materials (special metals), as well as software, will need to enter the international market with this solution. By analogy with nuclear power plants, the construction of which is implemented by Rosatom State Corporation all over the world. A substantial backlog for this has already been formed by Novatek when creating the Arctic Cascade technology for small-tonnage production. In case of successful testing of this technology on the fourth production line of Yamal LNG, it will be possible to use it with refinement on the Arctic LNG project. In the export version, this technology can be adapted to work in non-arctic conditions and can be successfully delivered worldwide. There is a demand for alternative Western LNG technologies. In particular, until 2012, Iran was building an LNG plant, which was conceived as a key element of Iran’s infrastructure for exporting LNG, but after sanctions were imposed on Iran to use licensed Linde technology and equipment was not delivered from Germany, the project was suspended.

4.3. Localization in Russia of shipbuilding for the needs of Arctic LNG projects

In order to develop a scientific and production base related to the development of the Northern Sea Route, the Ministry of Industry and Trade, together with Rosatom, has developed a program for the development of shipbuilding and equipment for the development of offshore fields. It was approved by the Government of the Russian Federation in March 2017. It provides for the construction of an atomic icebreaker fleet. In addition, for servicing Arctic LNG 2, it is planned to order Arc7 class gas carriers at the Russian shipyard Zvezda.

In 2018, the development of the technical project of the 120 MW nuclear-powered icebreaker-leader (project 10510) was completed, capable of ensuring year-round navigation in the Arctic, breaking ice up to 4.3 m thick, laying a corridor up to 50 m wide. The technical parameters of the designed icebreaker will allow for caravans NSR route at a speed of 10-12 knots. The construction of the lead nuclear-powered ship should be completed in 2027. In total, 3 icebreakers are planned to be built under project 10510.

In addition, the issue of building an additional 2 nuclear-powered ships of project 22220 at Baltic Shipyard JSC with the deadlines for putting the ships into operation in 2025 and 2026, respectively, is currently being studied.

In order to transport LNG and oil through the Gulf of Ob in the interests of the Atomflot FSUE, a 40 MW LNG icebreaker project is being developed. In total, it is planned to create 4 such vessels designed to work in pairs, which will ensure the necessary width of the shipping channel in the ice.

At the same time, one of the key problems of Russian shipbuilding is worth noting: the constant postponement of the deadlines for putting the ships into operation. The attracted credit financing for the construction of ships for the needs of LNG projects, in addition to the icebreaking fleet, poses serious challenges for domestic shipyards and, above all, those built by the Zvezda complex.

Among the largest investment projects to create new shipbuilding capacities it should be noted:

- Construction of a large-capacity shipbuilding complex of LLC “SSK Zvezda” (I and II phases) (implemented by PJSC Rosneft Oil Company). Based on the results of the full implementation of the project, it will become possible to build tankers of the Aframax and VLCC type, large-capacity gas carriers, various ice-class supply vessels, offshore platforms, as well as other equipment that is in demand for the development of offshore oil and gas fields and which was not previously massively or even created in Russia.

- Building of a center for the construction of large-capacity offshore structures LLC NOVATEK-Murmansk (Kola Shipyard). According to the results of creating a center for the construction of large-capacity offshore structures, NOVATEK-Murmansk LLC (Kola Shipyard) will make it possible to produce unique marine objects - gravity-type reinforced concrete platforms for LNG plants, drilling and production platforms for offshore projects in the western sector of the Arctic and large-capacity structures for ensuring the work of the Northern Sea Route.

The main task of localizing Arctic shipbuilding in Russia is the need to increase the share of value added remaining in Russia during LNG production, as well as to maximize the multiplier effect of creating LNG projects directly in the shipbuilding industry [13].
4.4. Diversification of LNG logistic sales channels. Implementation of the North-South transport corridor

In the context of growing geopolitical confrontation, as well as the systematic application of mechanisms of economic and political restraint of Russian gas against Russia, it is necessary to study the question of creating, in addition to the existing sea transport corridor along the West - East axis, a new river transport corridor along the North - South axis.

The North-South corridor implies the creation of a logistics chain for the movement of tank containers with LNG along the route: Gulf of Ob, Ob River, Irtysh River, Zaysan Lake, Black Irtysh River, China. The project will require substantial investment in the creation of coastal infrastructure, the modernization and construction of new hydraulic structures, dredging, as well as the creation of a river fleet for the transportation of large volumes of tank containers. The implementation of this transport corridor is possible taking into account the interest of the Chinese side in significant capital investments in the formation of this supply chain. Creating a water artery "Ob-Irtysh" will connect the NSR and the Silk Road into a single transport system [14].

4.5. Use of LNG as a transport fuel

The effective implementation of plans for economic development and Arctic sea transit will require large-scale development of port infrastructure, navigation, rescue and maintenance services for the NSR, as well as the creation of bunkering infrastructure throughout the NSR. The main barriers to using LNG as a bunker fuel are: safety of use, economics, level of infrastructure development, technical development, reliability of fuel supply.

Economic development in the Arctic will require technical re-equipment of the fleet, which may be associated with the widespread use of LNG as a bunker fuel. First of all, this is due to:

- A change in the supply chain of materials for the Norilsk industrial hub
- Development of Arctic oil and gas fields
- The activation of the arctic shelf exploration works
- LNG production in Yamal and the organization of icebreaking pilotage
- The state program for the development of the Arctic, including ensuring national security issues

All vessels for safe operation in the Arctic must be of the proper ice class and, despite global climate change and a decrease in ice cover, this requirement will continue for a long time. Most likely, all vessels built specifically for the Arctic zone will operate in the Arctic constantly without relocation to other areas.

The best option is to build new ships that can immediately use LNG.

At the same time, taking into account the large age of Russian vessels used in the Arctic zone, a promising option is the conversion of vessels to use LNG.

One of the restrictions when switching to LNG is the reduction in the volume of useful cargo transportation, which is associated with the placement of LNG storages on the vessel. However, the assessment shows that in the dimensions of the tanks for traditional fuels, LNG can be stored in sufficient volume to follow Arctic shuttle routes.

LNG can be supplied from large-scale projects in the Arctic - Yamal LNG and Arctic LNG. The geography of existing and possible LNG production centers is favorable for the organization of a sea transport corridor along the NSR, in which LNG will be used as bunker fuel.

The main obstacle to the development of the Arctic is the lack of infrastructure, but no less important is the lack of technical standards and regulatory documentation.

Shipping on the NSR will require significantly less fuel (compared with the Suez Canal) due to a significant reduction in the route between Europe and Asia, which allows to get additional income. The use of LNG will provide even greater economic benefits.

The use of LNG vessels for the transportation of oil, metals and other cargoes makes it possible to recoup the costs of using gas equipment and special engines for 2.5–5.5 years, which confirms the high competitiveness of LNG in the Arctic.
The intensive development of the Arctic will require ship fuel deliveries of up to 5-6 million tons per year, the creation of infrastructure for transshipment, storage and bunkering for the needs of transit and export of oil, coal and gas. In conditions when such infrastructure needs to be built from scratch, the Russian government should pay special attention to the active substitution of oil fuels for LNG, which will lead to lower transportation and transit costs, will protect the fragile Arctic ecosystem from pollutant emissions and from the consequences of accidental spills oil and oil products [15].

4.6. Gasification of Russian Arctic infrastructure

The Arctic zone of Russia is poorly developed, mainly economic development was carried out on the coast and along the main Siberian rivers. Nevertheless, to ensure the life of the Arctic, on the one hand, a reliable supply is required, which is called the "Northern Delivery" - the organization of the supply of goods, mainly fuel, to the Far North, Siberia and the Far East, on the other hand, the most environmentally advanced energy carrier. As part of the “delivery”, up to 6–8 million tons of fuel and lubricants and up to 20–25 million tons of coal are supplied annually. The share of the transport component in the cost of fuel reaches 70% (for an example of the supply of coal from Zryanyak to Pevek). The cost of coal reaches 8 thousand rubles per ton, diesel fuel up to 80 thousand rubles per ton and significantly exceeds the price of the domestic and world market.

Replacing the supply of coal and diesel fuel for heat and energy supply to consumers in the Arctic by LNG will reduce transportation costs and increase the reliability of energy supply while reducing environmental impacts and risks throughout the supply chain.

This requires not only the construction of LNG plants, but also the formation of a fleet of gas carriers and consumer LNG storage systems.

Depending on the location, volume of consumption, ground or floating solutions for the storage, regasification and production of electric energy can be used to supply fuel.

Both coast terminals and Floating Storage Regasification Unit (FSRU) have their own advantages and disadvantages, and their application depends on the specific requirements and needs in the target market. Recent trends show that new markets prefer floating terminals, e.g. Egypt, Jordan, Pakistan and Abu Dhabi, which have entered the LNG market through floating terminals recently.

Such floating solutions in industrial volumes are widely used in the world. For relatively small facilities there are project solutions but that are not widely used. Nevertheless exactly these small facilities have great future opportunities of implementation of LNG usage worldwide. This statement also applies to promoting LNG in the Arctic.

Placement of storage, regasification and energy generation facilities on ships, including non-self-propelled, avoids lengthy preparatory procedures for construction in the conditions of reduced daylight hours, on permafrost soils, avoids the need for large-scale dredging.

Increased competition and pressure on LNG producers leads to the search for new segments of the LNG market, and the Russian domestic market in the form of industrial consumers and ship bunkering can be an effective solution for Russian LNG development [16].

4.7. Gasification of the Murmansk region and Kamchatka using Arctic LNG

Another important element in the implementation of measures to develop LNG production is the construction of LNG transshipment terminals in Kamchatka and Murmansk. They will allow to maximize the Arctic potential while reducing operating costs for LNG transportation due to transshipment from Arctic vessels of Arc7 class to conventional gas carriers.

The development of transshipment facilities will also make it possible to comprehensively approach the tasks set by the Government of the Russian Federation to bring in the future the level of gasification of the regions of the Far East to the average Russian level, and will also help to solve the problem of gasification of the Murmansk region.

5. Conclusion

Summarizing the research we can conclude that, keeping in mind the growing global demand for LNG and the trend to replace traditional fuels with more environmentally friendly sources Russian Arctic LNG projects have very significant prospects for development.
However, it is necessary to keep in mind the key challenges for implementation of these projects. Successful response at the state and business level to these challenges will ensure further sustainable production of LNG to meet growing demand. The priority tasks are the localization of the production of critical equipment for medium- and large-capacity LNG production in Russia, the localization of shipbuilding for the needs of Arctic LNG projects as well as the formation of a new North-South transport corridor. The implementation of these tasks will minimize the external risks of the operating of Arctic LNG projects. In general, the widespread use of LNG as a motor fuel and resource for the production of heat and electricity will significantly improve the energy efficiency of the economy of both Russia and LNG consumer countries.

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6. References
[1] World LNG Report 2018 International Gas Union https://www.igu.org/sites/default/files/node-document-field_file/IGU_LNG_2018_0.pdf [Accessed 01 October 2019]
[2] Mitrov T, Sobko A, Sergeyev Z 2018 The transformed global market of LNG: How Russia not to miss window of opportunities? Energy center Skolkovo
[3] Konakhina N A Evaluation of Russian Arctic Foreign Trade Activity IOP Conf. Series: Earth and Environmental Science (Institute of Phys. Publishing Press) 180(1) 012018
[4] PAO NOVATEK http://www.novatek.ru/en/
[5] Didenko N I and Cherenkov V I 2018 Economic and geopolitical aspects of developing the Northern Sea Route IOP Conf. Series: Earth and Environmental Science (Institute of Phys. Publishing Press) 180(1) 012012
[6] Voronenko A G About the Ob-Irtysh project http://sco-khv.org/ru/publication_158/ [Accessed 01 October 2019]
[7] Klimentyev A Y, Knizhnikov A Y 2018 Potential of gasification of the Arctic zone of the Russian Federation with the liquefied natural gas (LNG) World Wide Fund for Nature (WWF)
[8] Klimentyev A Y, Knizhnikov A Y, Grigoriev A Y 2017 Prospects and possibilities of use of LNG for bunkering in the Arctic regions of Russia World Wide Fund for Nature (WWF)
[9] Didenko N I, Skripnuk D F, Mirolyubova O V, Sevashkin V and Samylovskaya E 2018 System of econometric equations of the world market of natural gas Int. Conf. on Information Networking pp 217-222
[10] Didenko N I and Romashkina E S Assessment of the Influence of the Extraction of Energy Resources on the Environment IOP Conf. Series: Earth and Environmental Science (Institute of Phys. Publishing Press) 180(1) 012014
[11] Skripnuk D, Kikkas K N, Safonova A S and Volodarskaya E B 2019 Comparison of international transport corridors in the Arctic based on the autoregressive distributed lag model IOP Conf. Series: Earth and Environmental Science (Institute of Phys. Publishing Press) 302(1) 012093
[12] Kikkas K N, Kulik S V, Krepkaia T N and Mokhorov D A 2019 Analysis of the economic relations of the circumpolar countries IOP Conf. Series: Earth and Environmental Science (Institute of Phys. Publishing Press) 302(1) 012093
[13] The development strategy of the shipbuilding industry for the period until 2035. Ministry of Industry and Trade of Russia http://minpromtorg.gov.ru/common/upload/docVersions/5b351b8fe0f2c/actual/strategy_sp.doc [Accessed 01 October 2019]
[14] Kikkas K N, Cherenkov V I, Berezovskaya I P and Anosova N E 2019 The application of the ARCH model for the assessment of transport routes in Northern Europe and Southeast Asia,
IOP Conf. Series: Earth and Environmental Science (Institute of Phys. Publishing Press), 302(1) 012100

[15] Merkulov V 2018 Analysis of advanced nuclear technologies applicable in the Russian Arctic
IOP Conf. Series: Earth and Environmental Science (Institute of Phys. Publishing Press) 180 (1) 012020

[16] Rodionov K 2018 Problems and prospects of the LNG projects in Russia.
JSC PricewaterhouseCoopers Audit (PwC)