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Industrial Gas Potential of the Western Arctic in the Strategic Perspective

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Abstract. The state of the mineral resource base of natural gas requires special control, as it is a strategic resource necessary for the sustainable functioning and development of the Russian Federation's economy, ensuring national security and defense, competitive advantage in foreign trade in hydrocarbons and deep-processing products, and meeting the domestic needs of high-tech sectors of the economy for hydrocarbon raw materials. An analysis of the state of the mineral resource base in terms of the country's energy and economic security was carried out, and an assessment of natural gas reserves replenishment based on the reproduction coefficient was given. A study was conducted on the level of resource potential and prospects for increasing the mineral resource base of natural gas in the Western Arctic. It has been determined that the requirement for guaranteed gas production necessitates a change in subsoil use strategy. The depletion of profitable Cenomanian deposits in several traditional fields has become an incentive to develop projects for the development of hard-to-recover natural gas reserves — Upper-Cenomanian and deep-lying Neocom-Jurassic and Achimov. It has been concluded that it is necessary to compensate for the depletion of profitable gas reserves in traditional gas production regions, primarily in the Nadym-Purskaya and Pur-Tazovskaya fields, by shifting the raw material base to the Yamal and Gydan regions; development of transit fields in the Kara Sea, Ob, Tazovskaya and Gydanskaya bays; development of complex hydrocarbon deposits within the developed fields of traditional gas production centers.
Keywords: *natural gas reserve reproduction, industrial gas-bearing capacity, hard-to-recover reserves, low-pressure gas*

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Introduction

One of the geo-economic instruments for Russia's spatial development, ensuring its foreign policy interests and strengthening its economic positions and national security in the Arctic, is the creation of conditions for the growth of the mineral resource base (MRB) and increasing the efficiency of industrial development of Arctic hydrocarbon deposits. The MRB Development Strategy,

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updated in 2024, defined areas of development, including through MRB growth; increase in the investment attractiveness of geological prospecting work (GPW); exploration of new deposits; development of identified deposits; introduction of modern technologies to increase the efficiency of field development, comprehensive extraction of mineral resources (MR), and deep processing of MR.

New geo-economic and political conditions are necessitating changes in domestic subsoil use. The adjustment to the development strategy affected not only production and processing, but also geological exploration, which is a driver of the development of the national economy and Russian regions.

The problems of natural gas reproduction and the search for technical and technological solutions for the development of complex hydrocarbon deposits in the Arctic region are addressed in the following works: [1, Laverov N.P., Bogoyavlenskiy V.I., Bogoyavlenskiy I.V.; 2, Kontorovich A.E.; 3, Kontorovich V.A., Kontorovich A.E.; 4, Markelov V.A., Cherepanov V.V., Filippov A.G. et al.; 5, Panikarovskiy E.V., Panikarovskiy V.V., Tulubaev A.B. et al.; 6, Skorobogatov V.A.] and others.

The spatial organization of oil and gas resource development and the assessment of factors determining the feasibility of oil and gas projects in the Arctic are the subject of research [7, Kazanin A.G.; 8, Ulchenko M.V., Fedoseyev S.V.; 9, Agarkov S.A., Saveliev A.N., Kozmenko S.Y. et al.; 10, Gautier D.L.] and others.

A significant contribution to the study of the influence of factors (climatic, infrastructural, anthropogenic, social, geopolitical, etc.) on the prospects for hydrocarbon production in the Arctic regions was made by scientists [11, Harsem, T., Eide, A., Heen, K.; 12, Kokko K.T., Buanes A., et al.; 13, Kozmenko S., Saveliev A., Teslya A.; 14, Semenova T.] and others.

The study and analysis of scientific sources and geological data show the need to update the economic assessment of industrial gas potential in terms of the prospects for the reproduction of natural gas reserves in the Arctic zone of the Russian Federation.

The aim of this study is to address the scientific problem of assessing the level of gas content and evaluating the prospects for natural gas reproduction in the Arctic zone of the Russian Federation in a strategic perspective.

The study is based on geological and field data from oil and gas companies, data from the State Balance of MR reserves, and the results of the author's previous research. The work uses statistical processing of geological and geophysical data, graphical and comparative-analytical methods of economic analysis.

Efficiency of development of Russia's natural gas resource base

Despite unprecedented sanctions in the energy sector and pressure on its partners, Russia continues to rank second in terms of natural gas production, although its share of global production has declined over the past two years (Table 1).

Table 1

Share of global natural gas production by top 10 exporting countries [1]

Country	Share of global natural gas production (excluding associated gas), %									
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
USA	20.5	21.1	20.7	20.3	21.9	23.4	23.9	23.4	24.5	25.5
Russia	17.2	16.7	16.8	17.3	17.4	17.1	16.5	17.3	15.3	14.4
Iran	5.1	5.2	5.7	5.8	5.7	5.8	6.1	6.0	6.2	6.2
China	3.8	3.9	3.9	4.1	4.2	4.5	5.0	5.2	5.5	5.8
Canada	4.6	4.6	4.7	4.7	4.6	4.3	4.3	4.3	4.6	4.7
Qatar	4.9	5.0	5.0	4.6	4.5	4.5	4.5	4.4	4.4	4.4
Australia	1.9	2.1	2.7	3.0	3.3	3.7	3.8	3.7	3.8	3.7
Norway	3.1	3.3	3.3	3.4	3.1	2.9	2.9	2.8	3.0	2.9
Saudi Arabia	2.8	2.8	3.0	3.0	2.9	2.8	2.9	2.8	2.9	2.8
Algeria	2.3	2.3	2.6	2.5	2.4	2.2	2.1	2.5	2.4	2.5

PJSC Gazprom has suffered the largest decline in production in recent years. In 2023, natural and associated gas production amounted to 358.95 billion m^3 (a decrease of 13.07%, compared to 30.4% for the period 2021–2023). A change in the structure of total gas production is observed. Independent gas producing companies have shown growth in production in recent years: PJSC NOVATEK — 3.13% for the period 2021–2023 (production volume in 2023 — 82.4 billion m^3), PJSC Rosneft — 43.28% for the same period (production volume in 2023 — 92.7 billion m^3). The Russian Ministry of Economic Development (MED) provided cautious forecasts for natural and associated gas production in 2024, with an expected annual increase of 4.8% compared to 2023, reaching 668.2 billion m^3. The reorientation of export supply directions, schemes and methods over the past two years has led to an increase in natural gas production in the development zone focused on natural gas liquefaction.

The effectiveness of MRB development in terms of the country's energy and economic security is characterized by a balance between the growth and depletion (production) of natural gas reserves. An assessment of the equilibrium ratio between the growth and depletion of natural gas reserves in category $A+B_1+C_1$ for 2014–2023 is presented in Figure 1.

[1] Source: compiled by the author on the basis of data from the Statistical Review of World Energy, 72nd edition, 2023. URL: http://assets.kpmg.com/content/dam/kpmg/nl/pdf/2023/services/statistical-review-of-world-energy-kleiner.pdf (accessed 21 September 2024).

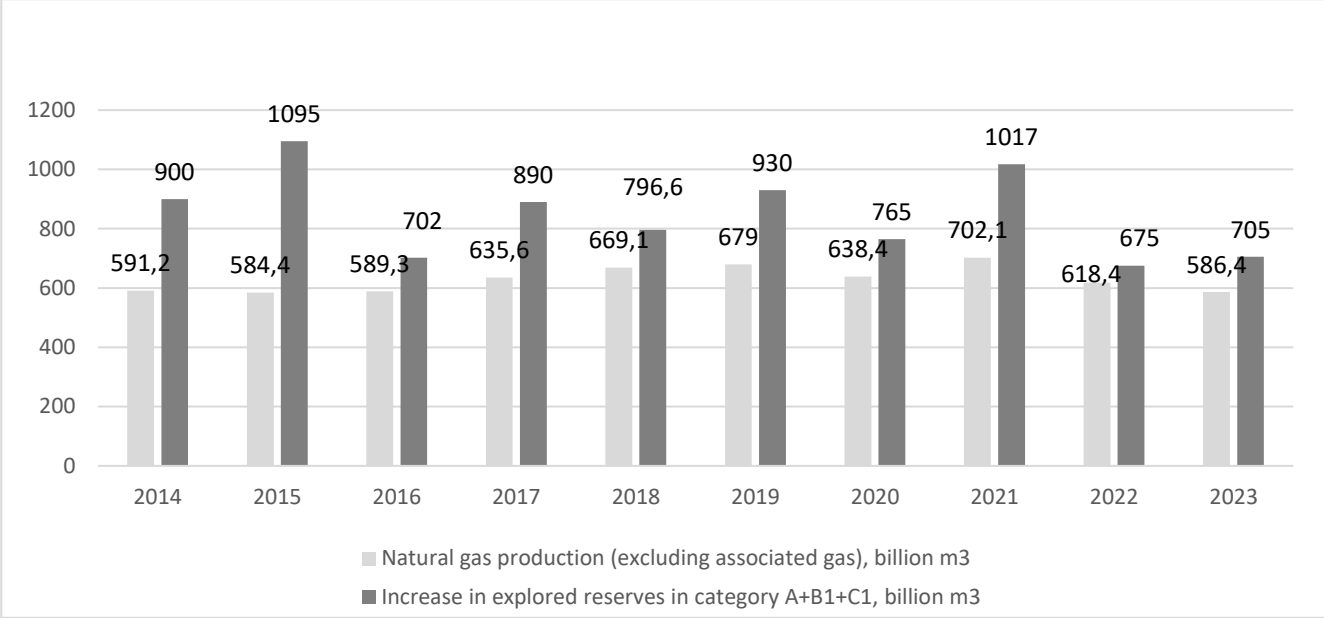

Fig. 1. Ratio between the growth and depletion of natural gas reserves in category A+B_1+C_1 for 2014–2023 (compiled by the author).

At the beginning of 2022, current recoverable natural gas reserves, according to the Russian Ministry of Natural Resources, remained stable and were estimated at 64.8 trillion m^3 (according to the State Balance, the volume of category A+B_1+C_1 natural gas reserves was 43.9 trillion m^3, and category B_2+C_2 – 20.9 trillion m^3). PJSC Gazprom accounts for 62.5% of natural gas reserves, PJSC NOVATEK — 13.2%, LLC RusGazAlyans — 9.3%, and LLC RusGazAlyans — 5%. Arctic deposits account for over 80% of the projected volume. The share of profitable reserves, according to the State Balance, is 62%.

The rate of natural gas reserve reproduction is characterized by the reproduction coefficient. Figure 2 shows the dynamics of the coefficient for the period 2014–2023.

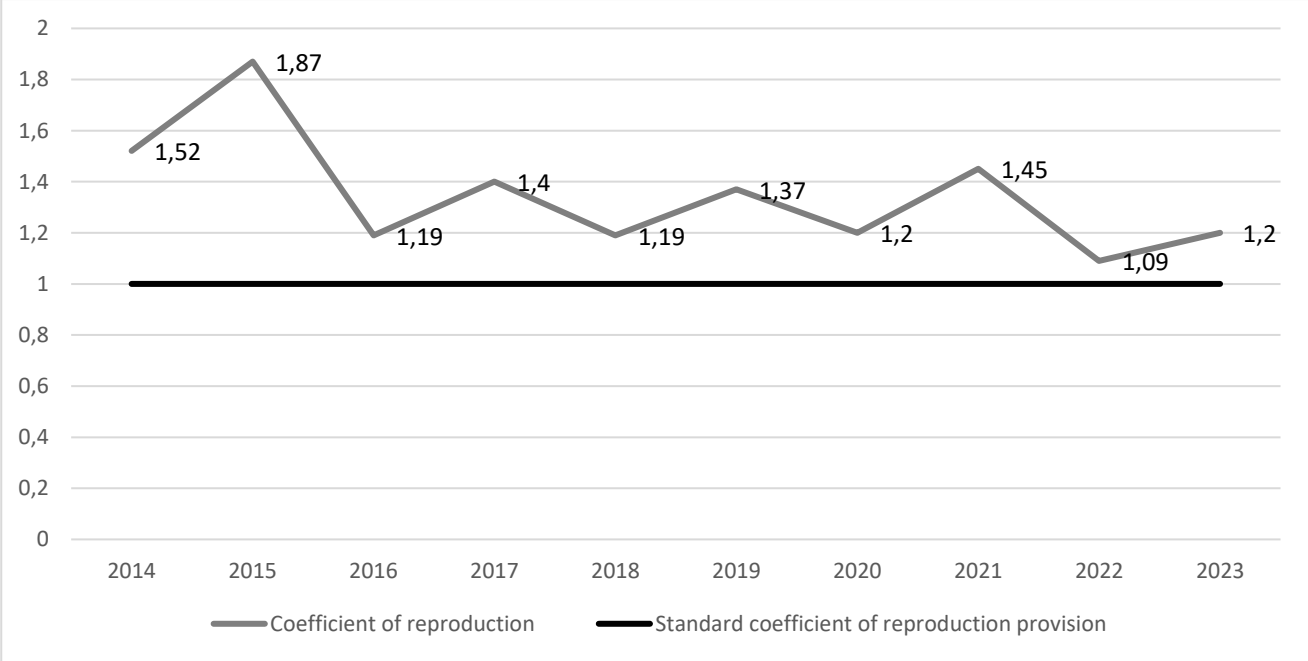

Fig. 2. Reproduction coefficient for 2014–2023 (compiled by the author).

As can be seen from the graph, there is a steady increase in natural gas reserves: according to the results of geological exploration and State Balance data, the increase in current recoverable natural gas reserves in the ABC_1+C_2 category from 2018 to 2022 amounted to 5 trillion m^3. The weighted average indicator of natural gas reserve reproduction for the period under study is 1.35. The parity between the growth and depletion of explored reserves is maintained, which ensures the reproduction of natural gas in the future [15, Shchegolkova A.A.].

Resource potential and prospects for the reproduction of the mineral resource base of natural gas in the Arctic zone of the Russian Federation

The main volume of gas exploration was carried out on the Yamal and Gydan Peninsulas, in the waters of the Baydaratskaya and Ob Bays, and on the Kara Sea shelf. The resource base of the Yuzhno-Tambeyskoe gas condensate field (Yamal OGR) was reassessed due to an increase in the area and commercial development of Jurassic deposits. The Achimov deposits at the Urengoyskoe oil and gas condensate field and the Yevo-Yakhinskoe gas condensate field (Nadym-Pur OGR) are being involved in commercial development. Further exploration of the Jurassic deposits of the Bovanenkovskoe and Tambayskoe industrial groups is underway. A gas deposit was discovered and put into production at the operating Yuzhno-Khadyryakhinskoe oil and gas condensate field (Pur-Taz OGR). The commercial potential of the Cretaceous deposits of the Arkticheskoe gas condensate field (Yamal OGR) has been confirmed. In 2020, unique fields were discovered on the Kara Shelf (Prednovozemelskaya OGR) — the Zhukov and Rokossovskiy gas condensate fields (with a total C_1+C_2 volume of 1.3 trillion m^3). In total, over 30 promising deposits have been identified on the shelf of this oil and gas region. In 2023–2024, no new hydrocarbon deposits were discovered in the AZRF, and the increase in natural gas reserves was ensured by the discovery of new gas deposits in the area of existing fields. Table 2 provides an assessment of the resource potential and prospects for increasing the natural gas reserves in the western Arctic.

Table 2

Prospects for natural gas reproduction in the Western Arctic fields [2]

Oil and gas regions (OGR)	Assessment of reserves and resources of natural gas (NG)	Level of exploration	Prospects for increasing natural gas MRB
West Siberian oil and gas province (WSOGP)			
Nadym-Pur Pur-Taz	120 fields with NG reserves are discovered. Initial NG reserves of the ABC_1+C_2 category are 32 trillion m^3. Remaining NG reserves are >10 trillion m^3 (including: high-pressure gas – 2.7 trillion m^3; low-pressure gas (LPG) – 3.8 trillion m^3; Turonian and Jurassic deposits >1 trillion m^3; Neocomian gas deposits >5.2 trillion m^3).	12 fields entered a stage of declining production, with overall regional depletion exceeding 75%. (Vyngapurovskoe and Medvezhye OGCFs have depleted 95–97%) Stage III of development.	New deposits are being developed within existing fields. Reserve volumes are being recalculated through the development of integrated projects for the extraction of complex, deep-lying hydrocarbon deposits (LPG; Achimov and Neocomian-Jurassic deposits).

[2] Source: compiled by the author.

Yamal	33 fields with NG reserves are discovered. NG reserves of the ABC_1+C_2 category are 16.3 trillion m³. The key dominant complexes are the Albian-Cenomanian (32.2%) and Aptian (42.8%). NG resources in the D_1+D_2 category — 7.1 trillion m³. Over 50% of these resources are concentrated in Jurassic and pre-Jurassic deposits.	Level of exploration — 70%. Initial/current NG reserves in terms of development are at the beginning of stage II (gas production is growing).	New deposits are being developed within existing fields. Reserve volumes are being recalculated as a result of exploration and development of Neocomian-Jurassic deposits.
Gydan	16 fields with NG reserves are discovered. NG reserves of the ABC_1+C_2 category are 2.2 trillion m³. NG resources in the $D_0+D_1L+D_2$ categories are 7.9 trillion m3. The Gydan OGR is divided into the following regional reservoirs: - Albian-Cenomanian deposits (northwest of the Gydan OGR, Taz Bay) – 18.2% of the initial reserves; - Middle-Upper Aptian deposits (southern Gydan OGR).	Level of exploration — 22%. Initial/current NG reserves in terms of development are at stage I (reserves have been identified but not developed)	Further exploration of deposits and development of new deposits within existing deposits are underway. Reserve volumes are being recalculated as a result of exploration and production.
Sverdrupskaya, Prednovozemelskaya, Yuzhno-Karskaya	8 fields have been discovered. NG reserves of the ABC_1+C_2 category are > 6.1 trillion m³. Natural gas resources of the $D_0+D_1L+D_2$ category are 47.5 trillion m³. The most promising is the Aptian-Albian-Cenomanian complex.	Level of exploration — 11.4%. The depletion rate of drilled reserves is 2.23%. Exploratory drilling phase.	Development is only possible after confirmation of NG reserves through geological exploration. Commercial development has been frozen due to high production costs, lack of logistics infrastructure, production and transportation technology.
Yenisei-Khatangskaya (within the AZRF)	"NG reserves of categories ABC_1+C_2 are 461 billion m³. NG resources of categories D_1+D_2 are 8.8 trillion m³. 95% of NG and condensate reserves are concentrated in Lower Cretaceous deposits in the Berriasian-Lower Aptian formations." [15]	Level of exploration <5%	"GPW and seismic surveys are underway to prepare the Vostok-Oil resource base (oil production and LNG production)" [15]
West and East Barents Sea oil and gas province (WEBOGP)			
Shtokman-Luninskaya, Yuzhno-Barentsevskaya, Finmarkenskaya	5 fields have been discovered. NG reserves of the ABC_1+C_2 category are > 4.7 trillion m³. NG resources of the $D_0+D_1L+D_2$ category are 28.3 trillion m³. The most promising is the Jurassic complex.	Level of exploration — 14.2%. Exploration drilling phase.	The Shtokmanovskoe GCF, the Ludlovskoe GF, and the Ledovoe GCF are ready for industrial development; their industrial development has been frozen due to high production costs, lack of infrastructure, production technology, and transportation.
Timano-Pechorskaya oil and gas province (TPOGP)			
Pechora-Kolvinskaya, Khoreyverskaya	This OGP is primarily oil-bearing. Exploratory drilling has proven commercial oil and gas potential, and two fields with NG reserves have been discovered. ABC_1+C_2 >73.7 billion m³. NG resources in the $D_0+D_1L+D_2$ category are 2.5 trillion m³.	Level of exploration — 2.9%. Exploration drilling phase.	Oil production is underway at the Prirazlomnaya offshore ice-resistant oil production platform. Commercial development of NG fields is possible only after their reserves are confirmed by geological exploration.

Since the development of the West Siberian oil and gas province, more than 21 trillion m³ of natural gas have been extracted, with current reserves estimated at 50 trillion m³. The MRB of this gas production center is at a mature stage of development, but individual oil and gas fields are at different stages, as the fields of the Nadym-Pur and Pur-Taz OGRs have entered a stage of declining

production. In this oil and gas region, exploration work is actively underway at traditional fields aimed at exploring the complex deep-lying deposits of the Achimov and Jurassic sediments, allowing for regular recalculation of recoverable reserves.

The Yamal OGR is showing growth in gas production, while new deposits are being developed within the existing fields, including the Jurassic deposits, allowing for reassessment of the region's potential reserves. The Gydan OGR is in the initial stages of development, with additional exploration underway. Like the Yamal OGR, the Gydan oil and gas region possesses significant resources, and its geographic location near the Gydan, Taz, Ob, and Yuratskaya Bays has made it attractive for development and implementation of natural gas liquefaction projects by PJSC NOVATEK [16, Ulchenko M.V., Bashmakova E.P.].

The Arctic shelf deposits have high potential; according to a number of Russian and Western experts, the volume of natural gas resources in the D_0+D_1L+D_2 categories amounts to 95 trillion m^3. Exploration and prospecting are actively underway, but there is currently no development concept, including proven technological solutions for the development of Arctic shelf deposits, either in domestic or foreign practice [15, Shchegolkova A.A.]. The Eastern Arctic OGRs are characterized by a low degree of geological and geophysical study; exploration work is unsystematic and is being conducted within the boundaries of licensed areas.

In order to maintain production at the level specified in the General Scheme for the Development of the Oil and Gas Industry until 2035 (approved in 2021), it is necessary to compensate for the depletion of profitable gas reserves at fields in traditional gas production regions, primarily in the Nadym-Pur and Pur-Taz OGRs [17, Shchegolkova A.A.].

Previous studies have identified the following elements of the natural gas MRB reproduction program:

- shifting the raw material base to the Yamal and Gydan regions;
- development of transit fields in the waters of the Kara Sea, Ob, Taz and Gydan Bays [17];
- development of complex hydrocarbon deposits within the boundaries of the developed fields of traditional gas production centers.

Previous studies have examined in detail the prospects of shifting the raw material base to the hard-to-reach areas of Yamal and Gydan, development of transit fields in the waters of the Kara Sea, Ob, Taz and Gydan Bays, and concluded that "it is necessary to expand the resource base through the development of accompanying fields in the Yamal and Gydan oil and gas regions and a number of coastal fields that have already developed production, processing, transport and social infrastructure, as well as through additional exploration of discovered and developed fields and deposits [17]".

Assessment of the prospects for developing Neocomian-Jurassic, Cenonian-Turonian, and Achimov deposits and low-pressure gas

Natural gas production in the West Siberian oil and gas province (WSOGP) was initially carried out at the unique Nadym-Pur and Pur-Taz fields, with the development of Cenomanian deposits containing dry gas that does not require processing and is free of methane homologs (C5+) and heavy hydrocarbons impurities. The depletion of profitable Cenomanian deposits (over 75% of total production in the region) led to an increase in the share of condensate-containing gas in the total volume of production. This can be observed at the Zapolyarnoe, Yamburgskoe, Urengoyskoe, and Yurkharovskoe OGCFs, where the main production sites are the Valanginian (Neocomian) and Achimov deposits, as well as the LP gas. In the Yamal OGR, the largest natural gas reserves are concentrated in the Aptian-Albian-Cenomanian strata (approximately 75%), while projected and prospective resources are concentrated in Jurassic and pre-Jurassic deposits. Natural gas development in Jurassic and pre-Jurassic deposits is being carried out jointly with the Lower Cretaceous deposits at the Yurkharovskoe OGCF, the Novoportovskiy cluster fields, the Yuzhno-Tambeyskoe GCF, and others. Natural gas in Neocomian-Jurassic deposits lies at depths of 1,600 to 3,300 m, and the deposits are gas condensate (methane content up to 80%). Unlike dry gas, it requires additional processing: separation from moisture, extraction of gas condensate, and cleaning of mechanical impurities. Table 3 presents an analysis of comprehensive projects by gas production companies for the extraction and industrial utilization of low-pressure gas and gas from Neocomian-Jurassic deposits.

Table 3

Projects aimed at developing gas from Neocomian-Jurassic deposits and low-pressure gas [3]

Deposit / Characteristics of deposits	Project features	Year of project implementation
Neocomian-Jurassic deposits		
Nadym-Pur and Pur-Taz oil and gas region, Stage III of development (Remaining NG reserves > 10 trillion m³, including Neocomian and Jurassic gas deposits > 5.2 trillion m³)		
Yurkharovskoe OGCF A transit field with access to the Taz Bay waters. The deposits are predominantly Neocomian-Jurassic, with depths (including Jurassic sediments) ranging from 1,000 to 4,400 m.	**PJSC Novatek, PC — 37 billion m³/year (NG), 2.7 million tons/year (GC)** • Use of ERD-wells (K_{ERD} 2.28) for onshore development; • Application of multi-stage hydraulic fracturing (HF) technology; • Commissioning of a gas and condensate integrated treatment unit (GTU); • Commissioning of a NG desulfurization unit (based on GTU); • Commissioning of a gas pipeline (GP) from the field to the junction point of the Urengoy-Yamburg gas pipeline interceptor and to the Yamburgskaya compressor station (CS), then along the central corridor of the Arctic GTS (two 52 km lines, total capacity of 54 billion m3/year); • Commissioning of a condensate pipeline (326 km, GTU of 3 million tons/year) to the Purovskiy GC processing plant; • Commissioning of an integrated pilot plant for methanol production (12.5 thousand tons/year);	Stage 1 — July 2004 Stage 2: September 2008 — Launch Complex 1, October 2009 — Launch Complex 2, October 2010 — Launch Complex 3, October 2012 — Launch Complex 4.

[3] Source: compiled by the author.

	• Application of environmental technologies — a climate technology project — to reduce the negative impact on the ecosystem (planned reduction in greenhouse gas emissions—255 thousand tons/year of CO_2 equivalent).	
Vostochno-Urengoyskoe OGCF, Severo-Esetinskoe OGCF. Neocomian deposits at depths of 1,700–3,200 m and Achimov deposits at depths of 3,400–4,000 m. Neocomian NG reserves: C_1+C_2 — 98 billion m³.	**OJSC Arcticgas (a joint venture of Novatek and Gazprom Neft), total PC: NG — 16.7 billion m³/year; GC — 4.5 million tons/year; propane-butane fraction — 1 million tons/year** • Application of multi-stage HF technology; • Application of cycling technology to maintain reservoir pressure; • Commissioning of a gas and condensate integrated treatment unit (GTU); • Application (based on GTU) of methanol recovery technology in a distillation column; • Commissioning of 1.5 km of field pipelines.	Commissioned into operation in 2019.
Zapolyarnoe OGCF Valanginian (Neocomian) deposits, depth 1,700–3,200 m. Neocomian NG reserves: C_1 — 735 billion m³, C_2 — 20 billion m³. GC reserves: C_1+C_2 — 137 million tons.	**Extraction of NG and GC from Neocomian deposits, total PC (two fields): NG — 15 billion m³/year; GC — 3 million tons/year, PJSC Gazprom** • 140 production wells were drilled (61 wells in the 1st field, 79 wells in the 2nd field), using directional drilling technology; • Use of HF technology with the injection of scale inhibitors; • Use of secondary formation penetration technology; • Use of an automated process control system (APCS) for the collection, processing, and storage of information on well operating parameters; • Commissioning of a gas and condensate integrated treatment unit (GTU); • Application (based on GTU) of low-temperature hydrocarbon separation technology with rectification; • Commissioning of a condensate pipeline (Zapolyarnoe — Novy Urengoy, 211 km, PC – 3.4 million tons/year) to the Novy Urengoy plant for the preparation of GC for transportation; • Commissioning of a gas connection from the field to the junction point to the Zapolyarnoe – Urengoy gas pipeline system (190 km).	Stage 1 UKPG-2V — April 2011 Stage 2 UKPG-1V — December 2012
Yamal oil and gas region, beginning of the Stage II of development Reserves of NG of the ABC_1+C_2 category are 16.3 trillion m³, the share of Neocomian and Jurassic deposits is 24%.		
Bovanenkovskoe OGCF, Kharasaveyskoe OGCF Neocomian-Jurassic deposits, depth including Jurassic sediments 1,700–4,400 m Reserves (Neocomian, Jurassic): NG C_1+C_2 — 1.8 trillion m³ GC C_1+C_2 — 222 million tons	**Kharasavey-Bovanenkovo project, Gazprom PJSC** • Application of multi-stage HF technology using a polymer-based insulating compound; • Commissioning of a gas and condensate integrated treatment unit (GTU); • Application (based on GTU) of low-temperature, medium-pressure separation technology; • Transportation of treated NG via the Bovanenkovo-Ukhta-Torzhok 1, 2, 3 gas pipelines; • Construction of a loading terminal for GC; • Transportation of GC via the Obskaya-Bovanenkovo-Karskaya-Ust-Luga railway line	
Novoportovskoe OGCF (Yamal OGR), primarily oil. Deposits are predominantly Valanginian (Neocomian) — 62.2%, Jurassic — 32.4%. NG reserves: $A+B_1+C_1$ — 267.9 billion m³; B_2+C_2 — 33.4 billion m³.	**The Novoportovskoe oil and gas cluster, PJSC Gazprom,** includes: **Novoportovskoe OGCF:** • Integrated multi-stage HF technology (up to 30 stages) with reusable sliding couplings with a sand carrier fluid containing proppant; • Commissioning of a gas and condensate integrated treatment unit (GTU);	October 2021

GC reserves: $A+B_1+C_1$ — 16.8 million tons; B_2+C_2 — 1.6 million tons.	• Associated petroleum gas (APG) compression (based on GTU) — 8.59 billion m^3; • Utilization of APG — 95%, including: APG injection into the reservoir — 89–93%; fuel for gas turbine power plants — 2–3%; • Commissioning of the Gaz Yamala gas pipeline connection — Yamburg — Tula I, II (115.5 km, including the underwater section of the gas pipeline — 58.4) [15] **Malo-Yamalskoe GCF:** • further exploration of the deposit is underway • design and survey work (D&S) for development has been completed **Khambateyskoe GCF:** • further exploration of the deposit is underway • design and survey work (D&S) for development has been completed NG transportation is expected via the gas pipeline connection of the Khambateyskoe – Malo-Yamalskoe – Blizhneno-Novoportovskoe – Novoportovskoe – Gaz Yamala GP.	
Malo-Yamalskoe GCF (Yamal OGR) Deposits are predominantly Jurassic—78.8%. NG reserves: $A+B_1+C_1$ —114.7 billion m^3; B_2+C_2 —114 billion m^3. GC reserves: $A+B_1+C_1$ —7.1 million t; B_2+C_2 —12.3 million t.		Start of industrial operation (project) – 2026
Khambateyskoe GCF (Yamal OGR) Deposits: Valanginian (Neocomian) — 100% NG reserves: $A+B_1+C_1$ — 15.7 billion m^3; B_2+C_2 – 18.7 billion m^3 GC reserves: $A+B_1+C_1$ — 1.2 million t; B_2+C_2 —1.4 million tons NG resources: D_0 — 247 billion m^3; GC: D0 — 20 million tons.		Start of industrial operation (project) – 2026
Yuzhno-Tambeyskoe GCF $(A+B_1+C_1)+(B_2+C_2)$ — 953.9+332.9 billion m^3. Albian-Cenomanian — 27.9%; Aptian — 47.1%; Valanginian (Neocomian) — 17.8%; Jurassic — 7.2%.	**The Yamal LNG project, PJSC NOVATEK, has 112 Neocomian GC wells and 10 Jurassic GC wells.** • Managed pressure drilling (MPD) technology is used; • ERD wells are used; • Multistage HF technology is used with propane injection at each stage.	The Yamal LNG project commenced in 2017. Commissioning of Neocomian-Jurassic wells — in 2022.
Low-pressure gas (LPG)		
Nadym-Pur and Pur-Taz oil and gas region, Stage III of development (Remaining NG reserves > 10 trillion m^3, including LPG of the Cenomanian deposits — 3.8 trillion m^3)		
LPG fields in the Nadym-Pur and Pur-Taz petroleum regions; LPG in the Cenomanian deposits — 3.8 trillion m^3.	**Extraction of residual reserves of NG and GC from Cenomanian deposits** • well operation using concentric and plunger lift (Medvezhye, Yamburgskoe, Urengoyskoe OGCFs); • use of modular compressor stations (CS), low-stage separation CS, vacuum CS, and wellhead CS for compressing LPG; • implementation of technical solutions to reduce liquid accumulation and its removal from gas gathering manifolds when supplying gas to booster compressor stations (BCS); • reconstruction of sections of the gas gathering network (reduction of pipeline diameters); • “use of a three-way valve for launching and receiving cleaning pistons” [18]; • consolidation of fields.	2011 — Medvezhye OGCF, 2012 — Vyngapurskoe OGCF, 2014 — Urengoyskoe OGCF, 2017 — Severo-Urengoyskoe OGCF 2018 — Yamburgskoe OGCF.

The production of natural gas from Neocomian deposits is carried out at fields currently under development. Therefore, despite the high cost of rich gas production, the availability of the necessary field infrastructure allows for its industrial use with a high level of profitability. In the Yamal and Gydan OGRs, sufficient gas potential for industrial development has been recorded, with a high prospect of discovering large natural gas deposits in the Neocomian-Jurassic sediments, larger in volume than the discovered Cenomanian ones, at the Severo-Kamennomysskoe, Kamennomysskoe-More, Obskoe, Semakovskoe and other GCFs [15, Shchegolkova A.A.]. The economic feasibility of exploiting LPG in the developed fields of the Nadym-Pur and Pur-Taz OGRs is noted, as this allows for extension of the life of the gas fields. However, its use as a raw material for the gas

chemical complex and for small-scale energy needs requires a comprehensive approach to the development of technological and design solutions.

The depletion of profitable Cenomanian deposits in a number of fields in the Nadym-Pur and Pur-Taz OGRs has stimulated the development of projects for the extraction of hard-to-recover natural gas reserves (HRR) — supra-Cenomanian (Cenonian-Turonian) gas, as well as deep-lying Achimov gas. Information on the gas content of Cenonian-Turonian deposits was obtained during exploration work at the initial stages of gas exploration in the Nadym-Pur and Pur-Taz OGRs. Experts [6, Skorobogatov V.A.], [19, Davydova E.S., Pyatnitskaya G.R., Skorobogatov V.A. et al.] claim that the supra-Cenomanian gas is of "Cenomanian" origin, which is confirmed by the geological and geochemical conditions of its distribution. They also note the insignificance of the volume of reserves of the supra-Cenomanian gas deposits (category $A+B+C_1$ – 1.2 trillion m^3, category B_2+C_2 – 0.3 trillion m^3), while the volume of category D_0 resources is estimated at 3.3 trillion m^3, which is incomparable with the natural gas deposits in the Albian-Cenomanian complex of the northern region of the WSOGP. Despite their shallower depth compared to traditional Cenomanian reserves, the geological and physical characteristics of natural gas in the Cenonian-Tourounian deposits are more complex. The low permeability of the reservoirs and the heterogeneity of the formations require the use of drilling technologies such as hydraulic fracturing (HF), horizontal and sub-horizontal, multilateral, and multi-bore wells.

Natural gas of the Achimov deposits is characterized by a complex geological structure with a depth of 3,500–3,700 m, low reservoir permeability, abnormally high formation pressure (up to 62 MPa) and temperatures [15], high content of intermediate hydrocarbons and paraffin fractions, high condensate content (220–450 g/m^3) in gas, which suggests the use of hydraulic fracturing (HF) technologies and gas condensate separation technologies [20, Davydova E.S., Izvekov I.B., Pyatnitskaya G.R. et al.]. The cost of extracting natural gas from Achimov deposits exceeds the cost of extracting Cenomanian gas by 10–15 times, according to various estimates [15, Shchegolkova A.A.]. Table 4 presents an analysis of comprehensive projects by gas production companies for the extraction and industrial utilization of gas from the supra-Cenomanian and Achimov deposits.

Table 4

Projects aimed at developing gas from the supra-Cenomanian and Achimov deposits [4]

Deposit / Characteristics of deposits	Project features	Year of project implementation
Post-Cenomanian deposits (gas from Turonian and Cenonian deposits) (Cenonian-Turonian natural gas deposits: 1.5 trillion m^3)		
Nadym-Pur and Pur-Taz oil and gas region, Stage III of development		
Yuzhno-Russkoe OGCF, Turonian gas (supra-Cenomanian deposits), stratum depth 800–850 m. NG reserves (Turonian) $A+B_1$ – 285.7 billion m^3, B_2 – 52.1 billion m^3.	**Turonian gas development program, PJSC Gazprom** • Application of innovative technology for drilling a directional well with a downward profile; • Application of multi-stage HF technology using a high-viscosity hydrocarbon-based gel; • Development of an innovative NG loss management system (IMS).	2007 – start of field exploitation; 2011 — implementation of the Turonian gas development program.

[4] Source: compiled by the author.

Kharampurskoe OGCF, NG reserves (Turonian): A+B_1 – 603.2 billion m^3, B_2 – 129.5 billion m^3.	**Turonian gas development program, total PC – 1 billion m^3/year, PJSC Rosneft** • design and survey works (D&S) for the construction of a complex of gas production facilities and gas pipeline connections were completed.	Experimental production began in 2014.
Zapolyarnoe OGCF, NG reserves (Turonian): A+B_1 — 206.8 billion m^3.	**Turonian gas development program, PJSC Gazprom** • further exploration and assessment of the industrial potential of the Turonian deposits is underway, design and survey work for the development has been completed.	Pilot production in 2021. Start of commercial operation (project) — 2026.
Medvezhye OGCF, NG reserves (Cenonian): A+B_1 — 9.7 billion m^3.	**Cenonian gas development program, PJSC Gazprom** • further exploration and assessment of the industrial potential of the Cenonian deposits is underway, design and survey work for the development has been completed.	Launch in pilot industrial mode in 2024.
Komsomolskoe OGCF, Yamburgskoe, Vyngapurovskoe Padinskoe GCF.		No data
Achimov deposits		
Nadym-Pur and Pur-Taz oil and gas region, Stage III of development		
Urengoyskoe OGCF, North of WSOGP in the Pur River basin, Purovskiy district Yamalo-Nenets Autonomous Okrug, Achimov deposits with a depth of 3400–4000 m: Initial NG reserves: C_1 – 1,389.491 billion m^3; C_2 – 282.268 billion m^3. Initial GC reserves (recoverable): C_1 – 251.389 million tons; C_2 – 49.571 million tons. Initial oil reserves (recoverable): C_1 – 15.004 million tons; C_2 – 26.549 million tons.	**Development of hard-to-reach Achimov deposits, total production capacity (five sites) — 37 billion m^3/year (Gazprom)** • Application of large-volume hydraulic fracturing (HF) technology in wells; • Use of a directional well with an S-shaped (up to 45°) borehole profile; • Use of subhorizontal wells with multi-stage HF; • Commissioning of a gas and condensate unit; • Construction of an oil pumping station (Urengoyskaya OPS); • Commissioning of the Urengoy-Pur-Pe gas pipeline (125 km).	Site: A1 — 2008 (PC: NG — 9.6 billion m^3/year, GC — 2.8 million t/year), A2 — 2009 (PC: NG — 8.7 billion m^3/year, GC — 1.5 million t/year), A3 — 2024 (PC: NG — 5 billion m^3/year, GC — 1.5 million t/year), A4/A5 — 2021 (PC: NG — 13.9 billion m^3/year, GC — 3.8 million t/year).

Currently, joint development of gas from the Cenonian-Turonian deposit and traditional reserves of the Cenomanian deposit is underway. The necessary production infrastructure allows for the maintenance of profitable production levels. The productivity of Cenonian-Turonian deposits has been established at most fields where Cenomanian formations are productive. A full assessment of the geological and recoverable natural gas resources of the supra-Cenomanian section is difficult, so its production is currently of no significant commercial importance. The production potential of supra-Cenomanian gas in the Nadym-Pur and Pur-Taz OGRs does not exceed 8 billion m^3 per year. As for the Yamal, Gydan, and Yuzhno-Karskaya OGRs, the prospects for commercial gas production in the supra-Cenomanian gas deposits are minimal [21, Cherepanov V.V., Menshikov S.N., Varyagova A.S. et al.].

The Achimov formation is currently considered the most promising. Achimov hydrocarbon deposits have been discovered at 51 fields in the Nadym-Purskaya, Pur-Tazovskaya and Gydanskaya OGRs. The geological reserves of the Achimov deposits are preliminary estimated at: 4.4 trillion m^3 of natural gas, 1.4 billion tons of gas condensate, and 10.4 billion tons of oil. The prospective development zone for the gas potential of the Achimov formation is 183,000 km^2.

Most of the Achimov gas is located in the Urengoyskoe OGCF (initial reserves of natural gas in category C_1+C_2 amount to 1.67 trillion m^3, geological reserves of gas condensate in category C_1+C_2 — 500.9 million tons). Significant reserves have been discovered at the Yamburskoe OGCF (a project for oil production from Achimov deposits is being developed) [4, Markelov V.A., Cherepanov V.V., Filippov A.G. et al.]. The joint development of Achimov and Cenomanian gas deposits and the multicomponent nature of Achimov gas make it possible to involve it in industrial development. According to seismic exploration and geological survey data, promising natural gas deposits have been identified in the Achimov formation at the Gydan OGR fields (Geofizicheskoe and Utrennee OGCFs; Gydanskoe, Trekhbugornoe, Tota-Yakhinskoe, and Shtormovoe GFs) and the Yenisei-Khatanga OGR within the Arctic Zone of the Russian Federation (Deryabinskoe GCF).

Conclusion

1. An analysis of the state of the MRB sector in terms of the country's energy and economic security was carried out using the reproduction coefficient indicator. The parity between the increase and depletion of proven reserves is maintained, which ensures the replenishment of natural gas in the future. The weighted average reproduction rate for the period under review is 1.35. A stable level of natural gas reserve reproduction is achieved not only due to reduced production against the backdrop of sanctions pressure, dependence on imports of technology, equipment and software, withdrawal of foreign partners, reduced investments, loss of the European pipeline gas market, but also due to growth in exploration and production, including in the AZRF. Over the past five years, the increase in current recoverable natural gas reserves in the ABC_1+C_2 category amounted to 5 trillion m^3. Despite the challenging geo-economic and political conditions, subsoil users continue to invest in hydrocarbon exploration and production, with this indicator remaining stable and averaging 300 billion rubles per year, while the share of the federal budget financing in 2023 amounted to 3.8% (11.3 billion rubles). The state funding program needs to be reviewed, primarily in terms of exploration drilling in promising, highly explored subsoil areas. This requires updating Russia's oil and gas map and regularly conducting geological and economic assessments of hydrocarbon reserves recorded in the state balance, taking into account production costs, profitability, and the availability of necessary technologies, as well as actualizing forecasts of resource volumes, considering the degree of their geological study. The expansion of the hydrocarbon industry is impossible without import substitution of exploration and production technologies and equipment. Dependence on imported drilling equipment (90%), laboratory equipment and software (90%), mining machinery (50%), and geophysical tools (10-30%) requires the development of a comprehensive state program aimed at achieving technological sovereignty in domestic geological exploration and gas production.

2. An analysis of the spatial distribution of resource potential and an assessment of the prospects for natural gas reproduction in the Arctic region were carried out. The Nadym-Pur and Pur-Taz oil and gas regions remain the strategic hub for gas production. They are in a mature stage of

development, with relatively high levels of commercially viable natural gas reserves in Cenomanian formations. However, some fields have entered a stage of declining production. To maintain production, subsoil users are developing programs to utilize new methods to intensify hydrocarbon production and to bring low-pressure and hard-to-recover natural gas reserves into commercial development.

New gas production centers are being established in the Yamal and Gydan OGRs. These regions are in the initial stages of development, with additional exploration and reassessment of potential reserves underway, including deeper Neocomian-Jurassic deposits. The high potential of the Yamal and Gydan OGRs is related to the implementation of geological exploration and prospecting aimed at converting the projected and prospective resources of mainland and transit fields into industrial reserves. The discovery of large natural gas deposits in Neocomian-Jurassic sediments, which are larger in volume than previously discovered Cenomanian deposits, has been noted to be highly promising. Overall, the forecast for the growth of category $B+C_1$ natural gas reserves in the Yamal, Gydan, and Yuzhno-Karskaya OGRs, as estimated by all subsoil users, is 17.5–18 trillion m^3 [17, A.A. Shchegolkova].

The Arctic shelf deposits also have high potential (category $D_0+D_1L+D_2$ resources — 95 trillion m^3), and active exploration is underway. The most significant constraint hindering the development and exploitation of Arctic shelf deposits is the lack of proven technological solutions, both in domestic and foreign practice, for the development of gas deposits at extreme depths in complex geological and industrial conditions in an ice environment. The Eastern Arctic's OGRs are characterized by a low level of geological and geophysical exploration. Geological exploration is unsystematic and is carried out within the boundaries of licensed areas. Currently, there is no commercial gas potential.

3. In the current geo-economic and political reality, the requirement for guaranteed gas production dictates the need to change the subsoil use strategies. The following elements of the natural gas reproduction program can be identified:

- *Shifting the resource base to the Yamal and Gydan regions.* The peculiarity of developing hard-to-reach areas in the northern and north-western parts of the WSOGP, where there are practically no developed fields, has determined the main directions for natural gas reproduction through the development of accompanying fields within the mineral resource clusters of the gas industry with existing industrial, transport and social infrastructure;
- *Involvement in the development of transit fields in the Kara Sea, Ob, Taz, and Gydan Bays.* As already noted, the main challenge in exploration work at offshore fields is the assessment of actual natural gas reserves. The development of these fields is hampered by the lack of proven technological solutions. In the future, expansion of the commercial gas-bearing zone will be achieved through the development of transit fields (onshore-offshore) using ERD wells with a large deviation from the vertical (K_{ERD} 2.28) to develop gas resources from the shore, following the example of the Yurkharovskoe OGCF;

- *Involvement in the development of complex hydrocarbon deposits within the developed fields of traditional gas production centers.* There are still prospects for an increase in natural gas reserves in the oldest Arctic gas production center — Nadym-Pur and Pur-Taz OGRs — through the development of deposits located above (Cenonian-Turunian) and below (Neocomian-Jurassic and Achimov) traditional Cenomanian gas, as well as low-pressure Cenomanian gas, provided that traditional (Cenomanian) deposits are jointly exploited at fields where the necessary industrial infrastructure already exists, which allows for maintaining a profitable level of production.

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