

Gasification as a way to combat air pollution in Krasnoyarsk

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Abstract. The main hydrocarbon fuel for the energy supply of the city of Krasnoyarsk is coal, local brown coal from Borodino. The energy supply of autonomous consumers of the city, and these are mainly private households on the left bank of the Yenisei, is carried out at the expense of their own boilers running on coal, wood and other solid fuels. This creates an acute problem of air pollution in the city, which affects the life and health of people. Natural gas is used only in liquefied form and in small quantities. One of the ways to reduce emissions of harmful substances into the atmosphere is gasification of the housing stock, which has become extremely relevant after the adoption of the Gasification Roadmap. Various options for household energy supply and gasification are considered and evaluated. The most profitable option for gasification is the construction of a branch from the main export gas pipeline Power of Siberia-2. However, it will be implemented no earlier than in 5-10 years, so other options for autonomous energy supply with lower emissions are offered. In addition, it is proposed to take into account the following effects when making a decision on the energy supply of households: the cost of using different types of fuel, inter-fuel competition, the interests of energy companies, the region, the population, greenhouse gas emissions, convenience, comfort and health of the population, the goals of the state for a comfortable environment.

1 Power supply of Krasnoyarsk

The main fuel for the power supply of Krasnoyarsk is coal, local brown coal from Borodino. They operate three thermal power plants Krasnoyarsk CHPP-1, Krasnoyarsk CHPP-2 and Krasnoyarsk CHPP-3 with a total electrical capacity of 1164 MW and 3664 Gcal/h of thermal power, as well as 35 boiler houses with a total thermal capacity of 3761 Gcal/h, which provide centralized heat supply to residential areas. The consumption of coal for the production of electricity and heat in the Krasnoyarsk Territory is about 25 million tons of fuel equivalent.

The level of gasification of the Krasnoyarsk Territory in 2021 is 12.8% of living space, with the level of gasification of rural housing stock 19.6%, and urban - 10.8%. Pipeline natural gas is available only in the industrial Taimyrsky Dolgano-Nenetsky District (the city of Norilsk and its environs), which is far from the populated (southern and central) part of the Krasnoyarsk Territory.

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At the same time, the provision of households with centralized heating in the region is 78.7%, in urban areas - 91.3%, and in rural areas - only 36.6%. A large number of private households, especially in rural areas, are self-heating (mainly using stoves or modern automatic solid fuel boilers) using solid fuel.

The energy supply of autonomous consumers of the city, and these are mainly private households on the left bank of the Yenisei River, which divides the city of Krasnoyarsk into two parts, is carried out at the expense of their own boilers running on coal, wood and other solid fuels [1]. Natural gas is used only in liquefied form and in small quantities.

Gas supply to the city of Krasnoyarsk is carried out by liquefied petroleum gas (the so-called bottled gas), which is used for food preparation [2]. Only 0.8% of households in the Krasnoyarsk Territory (Taimyrsky Dolgano-Nenetsky District) are provided with network gas, 24.4% - with imported liquefied and liquefied gas in cylinders. The remaining households do not have the opportunity to use domestic gas (3.3%) or do not need to use domestic gas (the remaining 71.5%).

Estimated volumes of demand, which are based on estimates of the replacement of "dirtier" than natural gas, solid fuels, amount to 19.3% of living space or about 222 thousand households [3].

While it is possible to install industrial filters at large energy facilities and reduce emissions, there is no regulation of private sector emissions. This creates significant negative effects on the environment [4].

One of the ways to reduce emissions of harmful substances into the atmosphere is gasification of the housing stock, which has become extremely relevant after the adoption of the Roadmap for the Development of Gasification of Regions [5]. The possibilities of gasification of the city of Krasnoyarsk and the Krasnoyarsk Territory have been discussed for a long time, various options are being considered [6], and the implementation dates are only indicative so far - 2028 [7].

2 Assessment of the attractiveness of gasification for the population

For the population, natural gas can be a competitive type of fuel with standardization and minimization of connection costs [8], which is assumed in the Roadmap. For the state, gasification can be a solution to the social and environmental problems of the regions. However, investments in gasification may not always be profitable for an investor.

The article provides separate assessments of the attractiveness of gasification for the population and the investor. To assess the attractiveness of gasification for the population, the cost of using different types of fuel to power a house with an area of 130 square meters is calculated, taking into account both current fuel and maintenance costs, and capital costs for the purchase of equipment, which is depreciated over 10 years. The duration of the heating season in Krasnoyarsk is 240 days. For calculations, the tariffs for housing and communal services established in the Krasnoyarsk Territory and the city of Krasnoyarsk and the cost of fuel in December 2022 are used.

Calculations are made for the following types of fuel: central heating, local lignite, firewood, electricity, liquefied gas in bottles/gasholders and potential pipeline gas.

Table 1 presents the results of estimating the cost of heating on different types of fuel for the conditions of Krasnoyarsk. The cheapest option is coal-fired heating, its cost, taking into account the cost of equipment, is 25-40 thousand rubles in year. The results of the calculations correspond to the current state using cheap local coals as the main fuel for household heating.

Firewood and network gas are next in cost. Heating on wood costs 45-55 thousand rubles per year, and on network gas - 45-105 thousand rubles in year. These costs take into account

the participation of households in financing gasification (at the minimum levels that are assumed under the Roadmap). If capital costs for equipment and construction of gas pipelines are reduced by optimizing overall costs, or they are partially or completely removed from consumers, then pipeline natural gas can become one of the cheapest types of fuel for heating. Gas heating will be slightly higher in cost (but the gas price proposed in the calculations is also one of the highest in Russia) than coal, but more environmentally friendly.

Table 1. The cost of heating on different types of fuel for households in Krasnoyarsk.

	Fuel price	Fuel cost, thousand rubles	The cost of equipment per year (depreciation for 10 years) ¹ , thousand rubles	The total cost of heating ² , thousand rubles
Liquefied gas (LPG)	20 rubles/liter	126,1	15-50	140-175
Electricity	2,3-3,5 rubles/kWh	84,2-130,7	15	100-180
Central heating	2 116 rubles/Gcal	65,5	0	65
Network gas	6-7 rubles/cbm	26,7-31,2	20-75	45-105
Firewood dry	2,9-3,5 rubles/kg	33,5-41,1	10-15	45-55
Brown coal	1,3-2 rubles/kg	15,0-22,7	10-15	25-40

¹ The cost of equipment and its maintenance is calculated, distributed over 10 years.

² The total cost includes the cost of fuel and the cost of equipment.

Source: authors' calculations based on [9-11].

Central heating is more expensive than the first three options - about 65 thousand rubles in year. Its cost can be reduced by modernizing CHPPs and boiler houses.

Heating with electricity and liquefied gas is 3-7 times more expensive than heating with coal, and in the current conditions cannot compete with cheaper fuels. However, if it is not liquefied petroleum gas (LPG) that is being considered, but liquefied natural gas (LNG), which is brought in, regasified and supplied to consumers at the price of conventional network gas (subsidized), then this heating option can be quite competitive for the consumer, since the payment for such the project will fall on the investor. However, someone has to organize and subsidize LNG production itself.

3 Assessment of the attractiveness of gasification for an investor

The issues of gasification of the Krasnoyarsk Territory and the city of Krasnoyarsk have been raised for a very long time, many researchers present their cost calculations, and according to some of the plans, network natural gas should have already been available in the region [12]. However, there are a number of reasons [13] for which the populated part of the Krasnoyarsk Territory is still not supplied with gas. Among them are high costs for the construction of gas pipelines and high tariffs for natural gas, as well as high competition of potential natural gas with local coal, a decrease in the cost of coal in the event of an increase in the use of natural gas, aggravation of social problems in the coal industry due to a decrease in the use of coal, unreliability operation of gas-fired thermal power plants at extremely low temperatures, and others.

The program for gasification of the region has not yet been adopted, and the current project involves the gasification of the populated part of the Krasnoyarsk Territory only with the help of LPG [14]. Therefore, these questions are still extremely relevant.

The article proposes to analyze different options and routes for gasification of the city of Krasnoyarsk, including:

- bringing the unified gas supply system (UGSS) to the city of Krasnoyarsk [15],
- gasification through the development of own fields in the Krasnoyarsk Territory,
- gasification by connecting the city of Krasnoyarsk with the Irkutsk gas production center,
- gasification through diversion from the Power of Siberia-2 export gas pipeline,
- gasification through LNG.

Let us consider these options and give their estimates (Table 2). One of the routes is to bring the unified gas supply system (UGSS) to the city of Krasnoyarsk. The boundaries of the UGSS can be with Proskokovo in the Kemerovo region or with Volodino in the Tomsk region. The length of such a gas pipeline will be about 600-700 km and will cost 90-110 billion rubles.

The next variant of the route is gasification through the development of own fields in the Krasnoyarsk Territory. There are several such deposits in the subject, within the framework of this article, Yurubchenko-Tokhomskiye and Kuyumbinskoye are considered the main ones. The distance to them is about 750-850 km, and the cost of building such a gas pipeline varies between 110-130 billion rubles. The development of these fields will make it possible to develop Krasnoyarsk's own gas production center in the southern part of the region (which has been on Gazprom's plans for many years).

The most expensive option is gasification by connecting the city of Krasnoyarsk with the Irkutsk gas production center (Kovykta field), since the length of such a route is about 2 times longer than the first two - 1500 km. Accordingly, the cost is also higher - 225 billion rubles, however, for the sake of completeness, we also consider this option.

Table 2. Route options for gasification of the city of Krasnoyarsk with network gas.

Route	Gas pipeline length, km	Cost, billion rubles	Note
From the Kemerovo/Tomsk Regions (UGSS)	600-700	90-110	Continuation of the ESG
Deposits of the Krasnoyarsk Territory (Yurubcheno-Tokhomskiye and Kuyumbinskoye)	750-850	110-130	Krasnoyarsk Gas Production Center
Kovykta deposit in the Irkutsk region. (Power of Siberia)	1500	225	Irkutsk Gas Production Center
Withdrawal from the Power of Siberia-2	50	10	Export gas pipeline to China

Note: calculation for a gas pipeline with a diameter of 700 mm and a capacity of about 5 billion cubic meters.

The cheapest option is gasification through the Power of Siberia-2 export gas pipeline. The distance from the city of Krasnoyarsk to the gas pipeline will be only 50 km; accordingly, the cost of its construction will be about 10 billion rubles. This is the most profitable option for the region, since the Power of Siberia-2 gas pipeline itself will pay for itself through export deliveries. However, a final decision on this route has not yet been made.

In the case of the construction of gas pipelines from the Kemerovo or Tomsk regions or from the fields of the Krasnoyarsk Territory, both state support and the search for sources of financing for such gasification will be required, as well as the establishment of high tariffs. With the participation of the state by 70% and Gazprom by 30% in investments of 28.5 billion rubles. and operating costs of 746.2 billion rubles. with a payback period of 22 years, the gas tariff will be 5.7 rubles per cubic meter [15]. Such calculations take into account natural gas

consumption of about 8 billion cubic meters per year, which is a fairly high figure (such volumes may require gasification of adjacent regions).

Another option for gasification can be considered gasification through LNG. According to the model calculations of Gazprom experts [16], gasification using LNG is more profitable than pipeline gas, with a distance of more than 160 km and an annual consumption of more than 600 million cubic meters, however, this will also require a significant increase in tariffs - up to about 8-9 rubles per cubic meter.

During the Krasnoyarsk Economic Forum, representatives of Gazprom announced plans to build an LNG plant with a capacity of 2 million tons to gasify the Krasnoyarsk Territory. Capital expenditures for gas production and plant construction, as well as gas transportation infrastructure, are estimated at 222 billion rubles [17]. The implementation period of such a project can be only 1-2 years. At the same time, only Novatek, not Gazprom, has its own implemented and operating technology for the production of LNG of such volumes.

Preliminary volumes of prospective consumption of natural gas in the Krasnoyarsk Territory due to gasification are estimated at about 3.5 billion cubic meters [15], of which up to 1 billion cubic meters can be households.

Estimation of the cost and economic efficiency of the projects described above allows us to draw the following conclusions (Table 3). The most attractive gasification project is gasification using the Power of Siberia-2 export gas pipeline, since it requires the lowest costs. The implementation of this project will make it possible to set a tariff of about 5.8 rubles per cubic meter, which is lower than gas tariffs in Central Russia, but higher than parity with coal prices. At parity, the price of gas should be no more than 5 rubles per cubic meter, which is almost impossible.

Table 3. Assessment of gasification projects in Krasnoyarsk.

Project	Costs, billion rubles	Advantages and disadvantages	Gas price for consumers, rubles/cubic meter	Payback period, years	Consumption, billion cubic meters	Cost price, rubles/cubic meter
Power of Siberia-2	10	+ payback through exports - dependence on foreign partners	5,8	4	3,5	4
Deposits of the Krasnoyarsk Territory	110-130	+ development of the Krasnoyarsk gas production center + revenue to the regional budget	6,9	18	3,5	2
Kemerovo/Tomsk region	90-110	+ development of UGSS to the east + developed Western resource base - high gas tariff	7,8	20	3,5	4
Kovykta field	225	+ development of the Eastern GTS - high gas tariff	10,4	21	3,5	2
LNG	222	+ fast implementation + lower infrastructure costs - high gas tariff	13,9	21	2,8	3,5*

*The cost of liquefaction is calculated based on the indicators of the large Yamal LNG project, so for small projects it may be higher.

Other gasification options require even higher gas prices. However, the first three options with gas prices up to 7.8 rubles per cubic meter correspond to gas prices, for example, in the Far East of Russia [18]. Therefore, when making decisions on gasification, it is also necessary to evaluate the environmental, budgetary and socio-economic efficiency of the projects under consideration, since these effects can only outweigh the economic efficiency.

Acceleration of gasification with a decrease in its cost will allow changing the payback parameters (gas price, payback period, and others).

4 Comprehensive efficiency of gasification for the population, government and business

Since gasification is not so much an economic as a social project, and the cost of natural gas exceeds the cost of coal in Krasnoyarsk, the assessment of the effectiveness of gasification must be made in a broader context. On the one hand, as part of a comprehensive analysis of the possibility of gasification and optimal energy supply, it is worth considering the cost of using different types of fuel, inter-fuel competition, the interests of energy companies, the region, the population, and other aspects of energy supply.

On the other hand, in addition to economic, social, environmental and other effects of gasification are important, which have a direct impact on the life of society, the state and business - greenhouse gas emissions, convenience, comfort and health of the population, the state's goals for a comfortable urban environment. The calculation of these effects is beyond the scope of this work. However, some such estimates already exist.

The most acute problem is air pollution in Krasnoyarsk. In [19], it was estimated that the level of lifelong risk to human health and life associated primarily with pollution of atmospheric air, drinking water and soil in the city of Krasnoyarsk corresponds to the upper limit of the range acceptable for professional groups, and is unacceptable for the entire population in general. The contribution of air pollution to the total mortality in the city is 10%, and the number of premature deaths is up to 112 cases per 100 thousand people. in year. Thus, it is possible to quantify the losses to the economy from premature death.

In [20], it is noted that the economic growth of the city of Krasnoyarsk can increase the consumption of fuel and energy. Along with this, there may be a gradual deterioration in fuel quality and an increase in pollutant emissions. The authors believe that it is necessary to establish restrictions on the composition of the fuel used, to introduce standards for maximum permissible emissions to solve the problem of air pollution.

Gasification can be a solution to the problem of air pollution, so considering the effects described above when assessing gasification can make coal-to-gas conversion projects more attractive, which will improve the environment and air quality, as well as public health.

5 Conclusions

Thus, when solving the problem of air pollution, it is worth paying attention to the following points. Firstly, gasification is an expensive and long-term solution - the most profitable option with the construction of a branch from Power of Siberia-2 will be possible no earlier than in 5-10 years. Thus, short-term (perhaps temporary) workable solutions are needed, such as LPG or other fuels.

For example, one solution to the problem of air pollution can be the use of coal briquettes, pellets and other types of bio- or solid fuels. In 2019, an experiment was carried out in which local coals were replaced with smokeless coal briquettes, the impact of harmful substances from which is 30 times lower than coal and an order of magnitude lower than firewood. [21] This option is almost never used in the city (therefore, it is not taken into account in the

calculations and should be worked out in more detail), but it can be a worthy energy supply option, given that the cost of briquettes can be comparable to the cost of firewood and coal with their higher calorific value and longer burning time.

Thus, different options have different time horizons, costs, emissions and other effects that should be taken into account when making a decision to combat air pollution in Krasnoyarsk.

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