SYNTHETIC FUEL VS. LNG

Comparative analysis of using synthetic fuel and LNG as motor fuels

Karpov A.B.,
Research Assistant,
Gubkin Russian State University
of Oil and Gas (NRU)

Kondratenko A.D.,
Engineer,
Gubkin Russian State University
of Oil and Gas (NRU)

UDC 622.76

AT PRESENT, THE MAIN SOURCE OF MOTOR FUEL IS OIL. THE INCREASE OF ENVIRONMENTAL REQUIREMENTS FOR MOTOR FUELS AUGMENTS THEIR COST; MOTOR FUELS FROM NATURAL GAS ARE BECOMING MORE WIDESPREAD. THIS PAPER PRESENTS A COMPARATIVE ANALYSIS OF THE USE OF FUEL PRODUCED BY GAS-TO-LIQUID (GTL) TECHNOLOGY AND THE PRODUCTION OF LNG FOR UTILISATION AS A GAS MOTOR FUEL

KEYWORDS: *alternative fuel, LNG, GTL, comparative analysis, natural gas.*

Over the past hundred years, oil has been an important source for energy production and is widely used in the transportation, industrial and domestic sectors. Currently, approximately 80% of global demand for transportation fuels (automotive, rail, air and marine) is met by derivatives of fossil fuels – oil.

However, over the past few decades natural gas has overtaken oil and has acquired the role of the major fuel source. This is largely due to the growth of LNG production, which has globalised gas markets. Furthermore, a growing awareness that cleaner technologies are vital to the future of the planet makes natural gas the primary source of fuel. Due to a combination of environmental issues, high oil prices and peak oil production, the development of cleaner alternative fuels and advanced power systems for vehicles has become a priority for many governments and vehicle manufacturers around the world.

The main alternatives to fossil fuels are:

- liquefied hydrocarbon gases (LHG)
- liquefied and compressed natural gas (LNG and CNG)
- synthetic fuel derived from natural gas or coal – methanol, dimethyl ether (DME), synthetic liquid hydrocarbons (SLH)
- ethanol
- hydrogen.

Environmental concerns about fossil fuels are driving the search for suitable alternatives. The use of hydrocarbon gas is widespread. When it is used, according to some estimates, greenhouse gas emissions are about 15% lower than use of petrol in vehicles. Additives or other agents are not required to increase the octane rating. A comparison of the levels of harmful gases emitted by vehicles operating on LHG and petrol is inconclusive, with test results indicating both higher and lower emission levels from vehicles.

The use of CNG due to the high octane rating of methane is an excellent option for spark ignition engines. The use of CNG significantly reduces particulate emissions, at the same time CNG for transport is being used more and more in the urban bus fleet sector. The main problem of CNG is its storage – due to its low boiling point, the natural gas must be stored at high pressure. In order to do this, metallic or metallic-composite cylinders are used, which reduce the imposed load and space in moderate vehicles.

FACTS

80 %

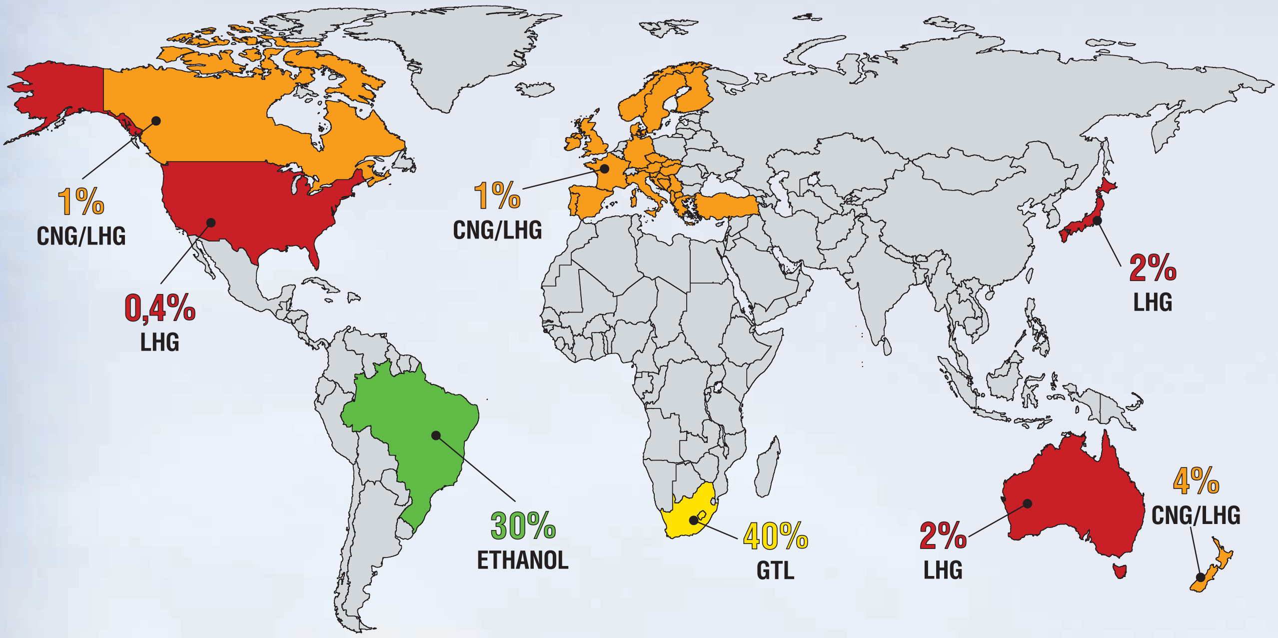
of global demand for transportation fuels met by oil

An alternative way to store natural gas is to liquefy it. In a liquid state, natural gas is 3 times denser than compressed CNG. Unlike CNG, which is stored at high pressure (200–250 atm.), and then reduced to lower pressure that the engine can handle, LNG is stored at low pressure (3–12 atm.) and simply evaporates in the heat exchanger in front of the fuel engine dispenser. Consequently, the mileage of a vehicle using LNG (without refueling) is three times more than that of a vehicle using CNG.

Ethanol is currently the most widely used alternative biofuel in the world. It is mainly obtained from crops containing sugar (for instance, sugarcane or sugar beets), or by pre-treatment of starch crops (maize or wheat). The positive environmental aspect is that, unlike oil, gas or coal, ethanol is a renewable resource. However, there are drawbacks: solubility in water which makes ethanol more difficult to separate, its production requires large areas of land, and also while reducing CO emissions, the emission of aldehydes increases. At present, ethanol production is 2–3 times more expensive than petrol production, making this type of fuel absolutely unprofitable.

A hydrogen vehicle is a vehicle that uses hydrogen as its primary source of energy for transportation. These cars usually use hydrogen in one of two ways: combustion or conversion in fuel cells. During combustion, hydrogen burns in engines in the same way as traditional petrol or methane. Upon conversion in a fuel cell, hydrogen is converted into electricity, which powers the electric motor. In both methods, the only by-product of the spent hydrogen is water, but

FIGURE 1. Main consumer countries of alternative fuels



nitrogen oxides can form during combustion with air. As of now, hydrogen is used as fuel only in space rockets. However, some car manufacturers are developing hydrogen engines, and the main technical difficulty is hydrogen storage and safety – hydrogen is extremely flammable in a wide range of air-fuel ratios.

Synthetic fuels constitute another group of alternative fuels. These include derivatives of natural gas or coal, namely methanol, DME and SLH. Currently, pure methanol is used in specially designed engines for racing cars, because its high octane rating allows the use of high compression, which gives significantly more power than traditional petrol engines. Although emissions of CO, hydrocarbons, and nitrogen oxides are lower, car-based methanol exhaust fumes contain more formaldehyde, which is carcinogenic. Methanol can also lead to more unburned fuel emissions of methanol and methane. Moreover, it is extremely toxic and therefore dangerous to handle. Another negative feature is its increased corrosion, which requires the modification of the fuel system of a conventional vehicle.

Dimethyl ether is a promising fuel in diesel engines and gas turbines due to its high cetane number. The simplicity of this compound with a short carbon chain results, upon combustion, in very low emissions of particulate matter, NO and CO. For these reasons, and also due to the absence of sulfur, DME meets the most stringent environmental requirements.

Another class of synthetic fuels that has received considerable attention recently is gas-to-liquid (GTL) fuel. GTL diesel fuel is produced from natural gas using the Fischer– Tropsch process.

GTL diesel consists exclusively of paraffin oils, with virtually no aromatic hydrocarbons or olefins.

FACTS

15 %

reduction of carbon dioxide emissions when hydrocarbon gas is used as fuel

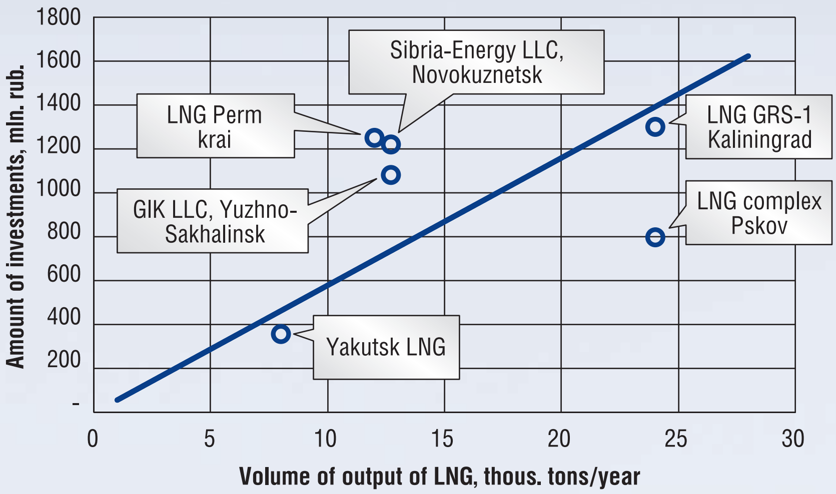
Additionally, GTL diesel fuel is almost sulfur and nitrogen free. The cetane number of GTL diesel fuel is significantly higher than that of petroleum diesel fuel – typically in the range of 70 to 75. GTL diesel fuel has poor lubricity and lubricating additives are required for commercial use. What is more, GTL fuel has poor low-temperature characteristics, which limits its potential use in cold climates. At the same time, a GTL diesel engine with a set of additives is fully compatible with existing diesel engines and can be used both as a replacement for conventional diesel fuel or as a mixture with it.

GTL diesel fuel leads to lower emissions of hydrocarbons, carbon monoxide, nitric oxide and particulate matter compared to conventional diesel. It is also worth noting that GTL diesel has no advantages in terms of CO_2 emissions.

Alternative motor fuels are currently widespread only in individual countries (Figure 1).

Other types of alternative fuels (ammonia, biodiesel, formic acid, etc.) will not be examined due to insufficient technological maturity and the impossibility of commercial use.

FIGURE 2. Volume of investments into low-tonnage LNG plants (measured in 2018 prices)



From the options considered above, two of the most promising and accessible in terms of application in the technological and economic sphere are LNG motor fuels and GTL diesel fuels.

The use of gas-based motor fuels is relevant for low-yield natural gas fields, as well as for the involvement of associated petroleum gas for refining

Monetization of gas using LNG is limited by its chemical composition and has narrow commercial applications in the regasified state, which distinguishes it from synthetic hydrocarbons.

LNG production is a key link in building the infrastructure for the production, storage, distribution and consumption of liquefied natural gas [1].

In modern installations for liquefying natural gas, technological plans are used based on the following main cycles:

- cooling cycles with throttling
- expander cooling cycles
- cascading cooling cycles with clean cooling agents
- single-threaded cascade cycles with the cooling agent being a multicomponent mixture

Often, various combinations are used in liquefaction methods, including elements of the above-mentioned cycles.

Currently, low-tonnage LNG technologies are the most effective – they are implemented in a compact modular design, located on an open area, not requiring significant construction and installation works, which leads to a decrease in investment.

Accurate data on the costs of LNG production is difficult to identify, since it can vary significantly depending on the location, LNG production volumes and logistics features. Data on the volume of investments in some Russian low-tonnage LNG plants is shown in Figure 2.

Liquefaction of natural gas is carried out for its transportation, and at the place of consumption, LNG is regasified, and currently the bulk of natural gas is used to generate energy. When using LNG as a motor fuel, regasification occurs in the vehicle's fuel system.

FACTS

3

times denser

liquefied natural gas (LNG) is 3 times denser than CNG

Today, in world practice, LNG is actively used, for the bunkering of sea vessels, and also for freight transportation as a motor fuel. The undisputed world leader in the use of LNG in transport is China, which has about 6 million units of gas engine vehicles and over 3 thousand LNG filling stations, making this country the largest gas motor market in the world (by comparison, the figure in Europe is 212 [2], in Russia – 2). The utilisation of natural gas in the transportation sector of China in 2018 amounted to about 36 billion cubic metres and according to forecasts, this value will have increased to 55 billion cubic metres by 2020 [3].

The main volume of consumption is accounted for by heavy LNG-powered freight trucks, whose number has already exceeded 240 thousand units in China. [4].

In Russia, the network of LNG fuel stations is virtually absent. Now LNG can only be refueled at two stations (Table 1).

Modern factory-made LNG-powered trucks have the same power and torque as diesel engines.

During the operation of Euro-V and Euro-VI ecological class trucks with 330 and 400 hp engines, it was found that the average LNG consumption is 25.9 kg/100 km. For gas vehicles, fuel consumption is about 15% lower than for diesel cars. Fuel consumption, among other things, is also affected by the type and weight of the cargo, route profile, refueling infrastructure, terrain and climate.

An important indicator for trucks is the driving range with one fill-up. Currently, the LNG supply aboard provides quite acceptable autonomy:

- KAMAZ – 1600 km;
- Ural – 1000 km;
- Scania – 1000 km;

TABLE 1. LNG fuel stations

LNG filling station	Location	Quantity	Stage	Year of commissioning
LNG GDS-1 Kaliningrad	Bolshoye Isakovo settl., Kaliningrad Oblast	1	Commissioned	2018
Moscow GPP	Razvilka settl., Moscow Oblast	1	Commissioned	2019
LNG fuel station project	Tyubuk settl., Chelyabinsk Oblast	4	CIW	2020
Multi-fuel filling station project	Kondratyevo, Leningrad Oblast	2	CIW	n.a.
LNG fuel station project	Bukharino village, Chelyabinsk Oblast	4	Project phase	n.a.
LNG fuel station project	Okulovsky area, Novgorod Oblast	2	Project phase	n.a.
LNG complex project	Petergrof, Leningrad Oblast	1	Project phase	n.a.
LNG fuel station project	Solnechnogorsk area, Moscow Oblast	n.a.	Pre-project phase	n.a.

- Iveco – 1500 km;
- Volvo – 1000 km.

Another important issue is the storage of LNG aboard the vehicle.

Natural gas must be supplied to the engine at the appropriate temperature, pressure and flow rate. In the simplest variant, in order to overcome hydraulic losses in heat exchangers and pipelines and to supply a sufficient amount of fuel to the engine, the supply system uses pressure in the tank.

In order to improve the flow characteristics, especially in the case of operating highly efficient spark ignition engines, the so-called warm LNG is used. Other, more sophisticated fuel systems are capable of using cold LNG.

Cold LNG is used at temperatures below -142 °C and 3–6 atm., while warm LNG is used at temperatures from -125 to -135 °C and 6–12 atm. Cold LNG has a higher density than warm LNG, and as a result more fuel with a longer drainage-free storage time can be aboard the vehicle. However, such an unsaturated fuel has low pressure, and auxiliary equipment is required for increase to take place before being supplied into the engine.

Refueling a vehicle with cold LNG compared with warm LNG increases mileage by 12 % and the time of drainless storage from 5 to 10 days (Figure 3).

The choice of the type of LNG filling station depends on traffic and the type of fueling machine. For example, in Europe, both cold-filling stations and warm-filling stations are used, and in particular, warm-type stations are common in Germany.

LNG vehicle operating experience shows reduced engine oil consumption. Gas, unlike diesel fuel, does not wash off oil from cylinder walls, and also it lasts longer. In practice, there is an increase in service life by about 30 % [6].

FACTS

200–250 atm

Pressure at which CNG is stored

Thus, as already noted, the only serious obstacle to the active widespread use of LNG is the small number of filling stations.

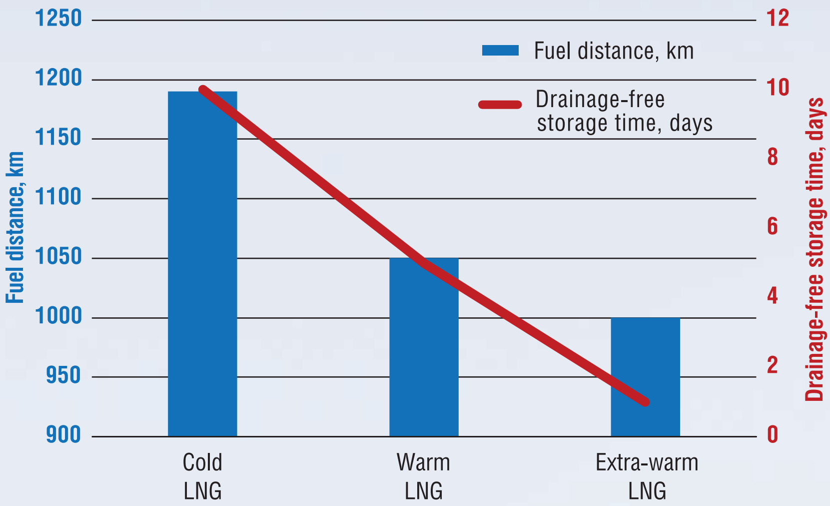
The chemical method of monetising natural gas for use as a motor fuel is to convert it to liquid hydrocarbons by means of the Fischer–Tropsch process. This process produces a wide range of products: fuels, base oils, LPG, naphtha and hard paraffins. Such a product line opens up more markets for sale, but it requires significant capital expenditures.

The technology for producing synthetic liquid fuels has existed since the 1920s. In 1923, German scientists Franz Fischer and Hans Tropsch developed the process of forming long-chain hydrocarbons by the chemical reaction of carbon monoxide and hydrogen based on a catalyst.

The development of this process was supported by the German government after the First World War to ensure energy independence. Subsequently, this technology allowed Germany during World War II to provide military equipment with fuel, thereby weakening the effectiveness of Nazi Germany's blockade.

The synthesis gas for this process was produced by gasification of the country's rich coal resources. Germany had 9 plants operating,

FIGURE 3. Effect of the type of LNG fill-up on vehicle distance and drainage-free storage time (based on data [5])



World capacities for the production of SLH are presented in Table 2.

The largest of the existing plants is the Pearl GTL in Qatar, with a total capacity of 140 thousand barrels per day. Initially, the cost of the plant was estimated at 5 billion US dollars, but the final costs were more than 3 times higher and amounted to 19 billion US dollars.

LNG production at the plant is based on Shell Middle Distillate Synthesis (SMDS) technology. The main products in this case are kerosene and diesel fuel, and additionally, ethane, LHG, naphtha, paraffins and base oils are produced.

which produced approximately 0.6 million tons of SLH per year.

After World War II, international conventions imposed obligations to dismantle SLH production. Plant equipment was either broken down into scrap metal, or exported from the country to the UK or the USSR.

Further on, the development of GTL technology was constrained by low oil prices. The total production of SLH in the world by 2010 amounted to less than 100 thousand barrels per day, which is comparable to one medium-sized refinery.

However, an increase in the service life of the catalysts used to produce liquid hydrocarbons from natural gas, an increase in the efficiency of the Fischer-Tropsch process, independence of natural gas markets from oil prices and a subsequent drop in natural gas prices, as well as global trends in the transition to low-impact fuels on the environment paved the way for the development of the SLH industry.

FACTS

3-12 atm

Pressure at which LNG is stored

The process of producing synthesis gas occurs due to the partial oxidation of purified natural gas with oxygen. The resulting synthesis gas, after cooling, is sent to the tubular reactors for the synthesis of fats. In total, the plant has 24 reactors, each containing tens of thousands of tubes having a cobalt catalyst. At the third stage, fractionation and hydrocracking of heavy paraffins takes place to increase the yield and quality of the obtained diesel fraction.

Products made from natural gas do not contain aromatic compounds, sulfur compounds or metals. This leads to a significantly smaller number of harmful carcinogenic compounds formed during the combustion

TABLE 2. Large plants for the production of SLH

Name of plant	Country	Licensor	Year of commissioning	Power based on SLH, barrel/day
Mossel Bay GTL	South Africa	PetroSA	1992	30,000
Bintulu GTL	Malaysia	Shell	1993	14,700
Mossel Bay GTL Expansion	South Africa	PetroSA	2005	15,000
ORYX GTL Phase 1	Qatar	Sasol	2006	32,400
Pearl GTL Phase 1	Qatar	Shell	2011	70,000
Pearl GTL Phase 2	Qatar	Shell	2011	70,000
GTL-plant in Ovadandepe settl.	Turkmenistan	Haldor Topsoe	2019	15,000
Total				**247,100**

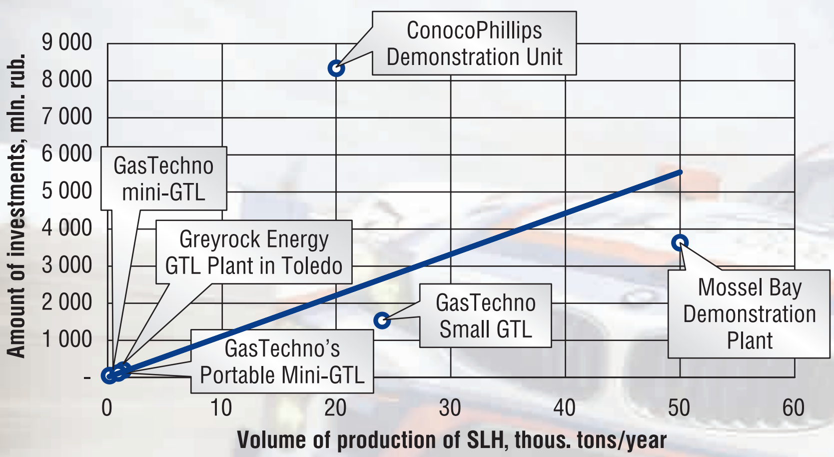
TABLE 3. Comparison of quality indicators

Indicators	Euro-5	Synthetic diesel fuel
Cetane number	>51	>70
Sulphur content, mg/kg	<10	n/a
Density at 15 °C	0,82-0,84	0,77
Polyaromatic hydrocarbons,% vol.	<11	<0,1
Temperature limit of filterability, °C	-20..-38	-27
Boiling temperature 95% vol., °C	<360	340
Lubrication capability, μm	<460	457

TABLE 4. Examples of low-tonnage GTL-plants [7–10]

Plant	Country	Year of commissioning	Output by SLH, ton/year
ConocoPhillips Demonstration Unit	USA	2003	20 000
Mossel Bay Demonstration Plant	South Africa	2011	50 000
Greyrock Energy GTL Plant in Toledo	USA	2011	1 400
GasTechno's Portable Mini-GTL	USA	2013	190
GasTechno mini-GTL	project		950
GasTechno Small GTL	project		24 000

FIGURE 4. Volume of investments into low-tonnage GTL-plants (2018 price range)



of fuel in the car engine than when using fuel obtained through oil refining.

Daily, such a plant produces 50 thousand barrels of diesel fuel, as well as 30 thousand barrels of high-quality base engine oils of the 3rd group.

A comparison of synthetic diesel fuel quality indicators with the requirements of GOST 32511-2013 (EN 590:2009) for 5th grade diesel fuels is presented in Table 3.

The next large liquid hydrocarbon production plant was launched only in July 2019 in the village of Ovadandepe in Turkmenistan. Unlike the plant built in Qatar, the main product of this plant is petrol, the production of which is 600 thousand tons/year (diesel fuel capacity – 12 thousand tons/year). The total yield of liquid hydrocarbons is approximately 15 thousand barrels per day, and the capital costs for the construction of the plant amounted to 1.7 billion US dollars, which correlates with the specific capital costs for the plant in Qatar.

However, such installations require a large amount of natural gas and are not suitable for monetization of small fields. For this purpose, low-tonnage plants for the production of synthetic hydrocarbons have become widespread, presented in Table 4.

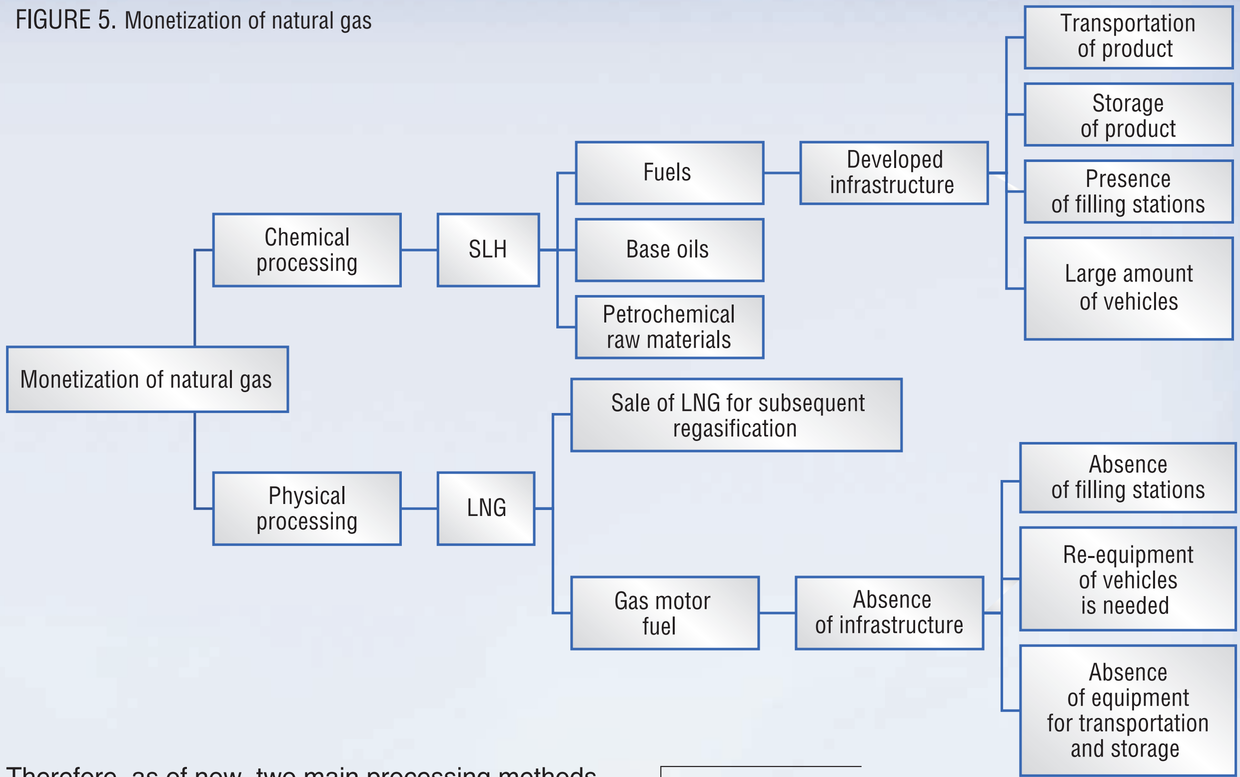
GTL low-tonnage plants have higher specific capital costs, however, their use can be advantageous in the presence of cheap raw materials. Data on investments at prices from 2018 are presented in Figure 4.

Due to the high capital investments, the feasibility of constructing a GTL plant is only possible at a low cost of natural gas, which is why global oil and gas companies currently prefer to invest into traditional methods for producing liquid fuels.

For example, the planned cost of the Amur Refinery, the construction of which was postponed for an indefinite period in 2019 due to lack of raw materials [11], amounted to approximately 120 billion rubles, which is slightly less than 2 billion US dollars. These investments are commensurate with the costs of the GTL plant in Turkmenistan.

The planned capacity of the refinery for raw materials is 6 million tons per year. Thus, with the same capital costs for the construction of a refinery and a GTL plant, the capacity of the former will be several times greater, ensuring lower production costs and quicker payback.

FIGURE 5. Monetization of natural gas



Therefore, as of now, two main processing methods can be distinguished as options for monetising natural gas reserves for utilisation as motor fuels: the physical method – production of liquefied natural gas (LNG) and the chemical method – production of synthetic liquid hydrocarbons (SLH) based on the Fischer-Tropsch method (Figure 5).

Both methods, undoubtedly, have advantages, but they are not without drawbacks. In terms of LNG, this means the need to re-equip automobiles and the underdeveloped sales infrastructure; in terms of GTL, this implies large investments into production.

By way of comparison, let us consider these two options as an example of a small company having a natural gas field with a production cost of 2 thousand rubles/thousand m^3 and its own fleet of 20 truck tractors, having a mileage of 1000 km, due to minimum fuel distance of modern LNG vehicles.

FACTS

2-3

times higher

ethanol production is 2–3 times more expensive than petrol production

If the company selects an investment project for converting transport to LNG, the following costs will be required (Table 5).

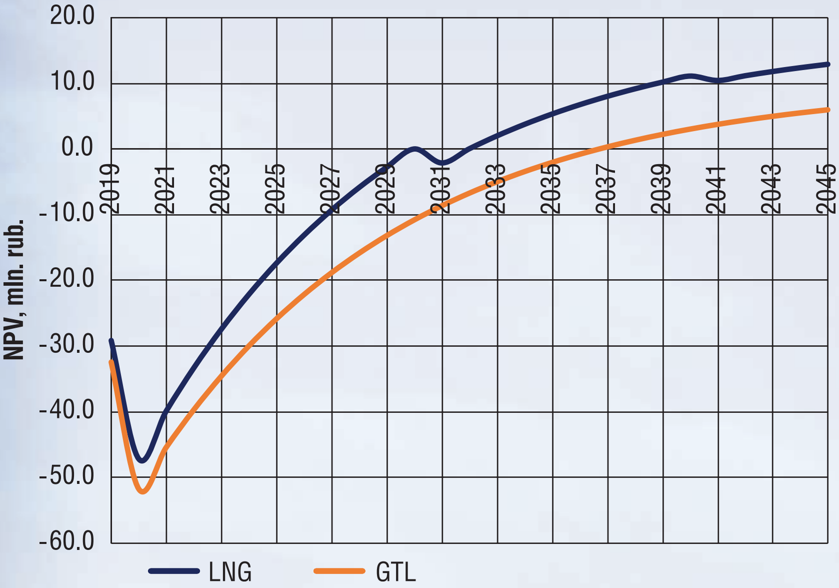
For subsequent calculations, it was assumed that the annual mileage of each truck will be 50 thousand km. Based on these initial data, the unit capacity per year was calculated and capital expenditures were determined based on Figure 2. Furthermore, in order to switch to gas engine fuel, apart from converting equipment, it is necessary to provide fueling for the vehicle. And since at present the LNG filling-station infrastructure is poorly developed in Russia, the company will have to inject additional investments for the construction of a filling station and a semi-trailer cistern for LNG transpaortation from the plant to the filling station. The service life of the relevant trucks was assumed to be 10 years (after this period, collateral costs for re-equipment of trucks were taken into account).

Conversely, in order to implement the GTL project under the same conditions, only investments into a sy nthetic fuel production unit with a capacity of 425 tons will be required.

TABLE 5. Capital costs for transition of equipment and construction of installation

Unit	Characteristics	Volume of investments, mln./rub.
LNG unit	32,5 kg/h	15
LNG filling station	1	11
Re-equipment of trucks	20	13
Semitrailer-cistern for LNG transportation	1	5
TOTAL		**44**

FIGURE 6. Comparison of NPV dynamics



A comparison of the dynamics of net present value (NPV) during implementation of these investment projects is presented in Figure 6.

During 25 years of operation, both options have a positive NPV. However, in the case of the LNG project, the net present value is more than twice as high and the discounted payback period is 5 years less.

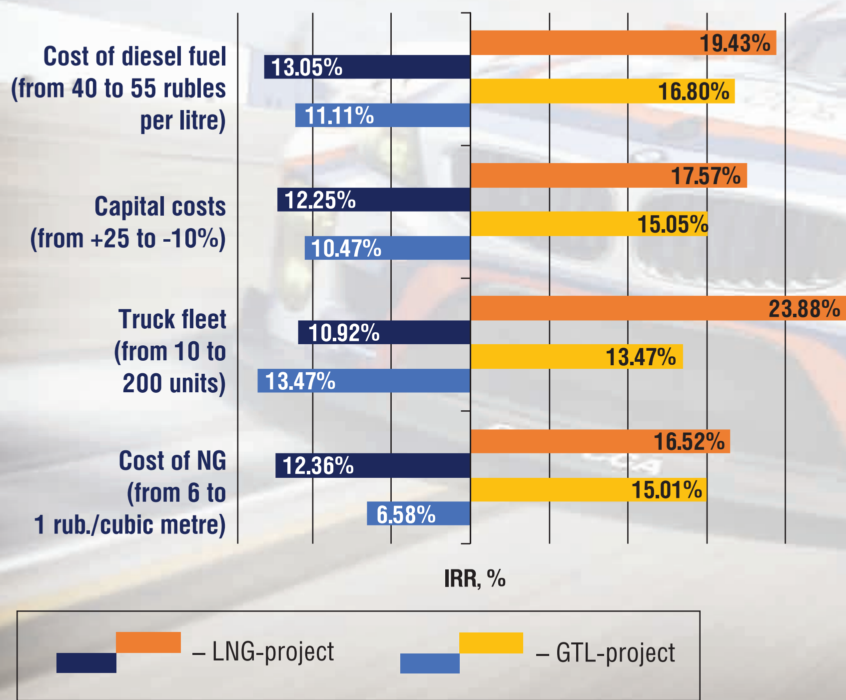
Figure 7 shows the sensitivity analysis of the internal rate of return (IRR) depending on changes in various parameters.

FACTS

Cetane number

of GTL diesel fuel is significantly higher than petroleum diesel fuel – ranging from 70 to 75

FIGURE 7. Sensitivity analysis of investment projects



As can be seen from these diagrams, the project which is more resistant to external factor changes is the method of using LNG as a gas engine fuel. The only exception is the truck fleet factor (fuel consumption), which is less sensitive to change, even in regard to increasing payback during augmented productivity.

Thus, when comparing the alternative motor fuels GTL diesel and LNG, the most promising option is that of liquefied natural gas (LNG) used as a motor fuel. The results obtained during research show that, if there is a source of inexpensive natural gas, both options can be used. Nonetheless, despite the costs of creating built-in infrastructure for refueling trucks with liquefied natural gas, the option with LNG utilisation not only supersedes synthetic diesel fuels, but also allows to save a significant amount of money. ●

References

1. *Technology for producing low-tonnage LNG with two cooling circuits // Business journal Neftegaz.ru No. 2, 2018. – P. 50–54.*
2. *NGVA Europe Stations map [Internet resource] URL: https://www.ngva.eu/stations-map/ (accessed 05.08.2019).*
3. *China Energy Statistical Yearbook 2015.*
4. *Hao H., Liu Z., Zhao F. Natural gas as vehicle fuel in China: A review. Renewable and Sustainable Energy Reviews, 2016, No. 62, P. 521–533.*
5. *A review of liquefied natural gas refueling station designs / Sharafian A. and. etc. // Renewable and Sustainable Energy Reviews, 69. – 2017. – 503–513.*
6. *LNG in European vehicles [Internet resource] URL: http://gazpronin.ru/LNG4Trucks_in_Europe.pdf (accessed 05.08.2019).*
7. *GasTechno's Portable Mini-GTL plant a roaring success [Internet resource] URL: http://www.globalchemicalprice.com/blog/gastechno-s-portable-mini-gtl-plant-a-roaring-success (accessed 05.08. 2019).*
8. *A.M. Kuznetsov, V.I. Savelyev, N.V. Bakhtizin GTL Industry: Status and Prospects // Scientific and Technical Bulletin of Rosneft Oil Company. 2012. No. 2 (27). P. 44–49.*
9. *Elvirosa Brancaccio GTL: Small Scale and Modular Technologies for Gas to Liquid Industry [Internet resource] URL: http://www.oil-gasportal.com/gtl-small-scale-and-modular-technologies-for-gas-to-liquid-industry / (accessed 05.08.2019).*
10. *Gas Technologies LLC Product Data Sheet [Interent resource] URL: https://gastechno.com/pdf/GasTechno-Mini-GTL-Data-Sheeet.pdf (accessed 05.08.2019).*
11. *RosBusinessConsulting [Internet resource] Construction of the Amur Oil Refinery postponed due to lack of raw materials URL: https://www.rbc.ru/business/07/02/2019/5c5ad4c59a794749e2d0e683 (accessed 05.08.2019).*