

Analysis of fuel energy efficiency for motor transport in Kazakhstan

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Abstract. The purpose of the research was to identify a promising fuel material for vehicles. At the same time, an analysis of previous studies allowed us to say that gas fuel is the safest for the environment and the most economically profitable for Kazakhstan. The characteristics of gas mixtures were analyzed and plant-based biofuels were identified as the final energy-saving fuel option. Such results were obtained that it can be concluded: Kazakhstan has huge reserves of natural gas, but from an environmental point of view, to maintain balance, biogas should become a rational biofuel for the automotive industry.

1 Introduction

Now the construction of roads is very intensive, the number of parking lots is increasing, the number of cars is constantly growing, and this is changing the infrastructure of small and large cities. Cars dominate both during working hours and during people's leisure time. Despite the availability of various mass transportation vehicles, the car still remains indispensable [1-17].

Road transport occupies an important place in the country's unified transport system. It transports more than 80% of 80% of all cargo transportation uses motor vehicles. Road freight transportation has a number of advantages, first of all, the versatility of cargo, door-to-door delivery, greater reliability and good speed. Despite the poor quality of roads, preferences are given to road transport in Kazakhstan.

The level of motorization has the same tendency to increase. Every year the total number of vehicles continues to increase. The production of new cars occurs at a very high pace - 124 thousand per minute roll off assembly lines around the world [1]. The number of cars with mileage and a service life of more than 15-20 years is increasing at the same speed. The number of agricultural machinery that uses diesel is also increasing.

According to International Energy Agency (IEA) Statistics, 327 million MW are consumed around the world every day. Humanity has long known and strived to use renewable energy, such as solar or wind energy, but this represents only 17.6% of all energy consumed (Fig. 1).

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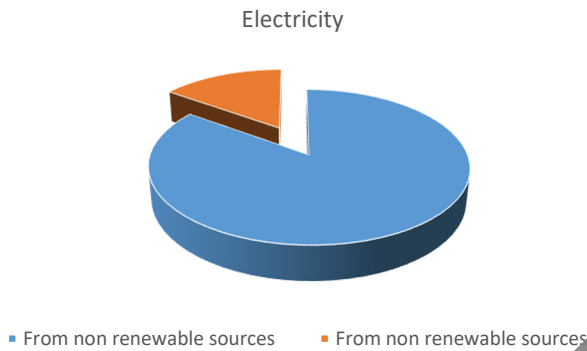


Fig. 1. The ratio of electricity obtained from various sources

At the same time, it's no secret that oil remains in the bowels of the earth for a maximum of 40-60 years. At least 60 barrels of oil are produced around the world every day. Obviously, the problem of using and obtaining energy is relevant.

If we consider only motor vehicles, we can highlight the main types of fuel used in Kazakhstan: gasoline, diesel, liquefied petroleum gas and compressed natural gas.

Converting cars from gasoline or diesel fuel to gas energy is a well-known technology. In 1920, 4 gas-powered cars were produced at the Gorky Automobile Plant. The costs of purchasing and installing gas equipment pay off after 15–20 thousand kilometers. But there are other positive indicators of switching to gas fuel:

- increases the service life of exhaust gas equipment;
- the mileage of the internal combustion engine increases;
- engine oil can be changed less frequently and its efficiency increases;
- the main advantage is that the exhaust gases meet the requirements of international high-quality fuel.

It is important that the use of gas fuel can significantly reduce the production and consumption of liquid petroleum fuel. The operation of one car running on gas fuel provides the release of liquid motor fuel from 5 to 10 tons per year for a light-duty car [2]. In addition, when compared with gasoline, the gas version will emit 1.5 times less toxic substances into the atmosphere during the same time period of cargo transportation under equal accompanying conditions.

In the late 40s and early 50s, the USSR mastered the production of gas-cylinder vehicles using compressed natural gas. Several thousand of these vehicles were operated for several years in Ukraine and the Volga region, areas that were sufficiently supplied with natural gas at that time [3]. A clear example is countries such as the Netherlands, the USA, Japan and Germany. It is in these countries that a lot of natural gas is used for vehicles.

If we consider the physicochemical properties of gas fuels, we can safely say that they are superior to gasoline ones. Main advantages in the following parameters:

- allow you to achieve higher power and fuel-economic indicators than gasoline engines similar in the way they organize the work process. Specially designed gas engines are superior to gasoline engines in terms of specific power indicators, and are close to diesel engines in terms of fuel efficiency;
- in terms of environmental emissions, they are significantly superior to gasoline.

Table 1. Comparative characteristics of propane, butane, methane and gasoline

Options	propane	butane	methane	gasoline
Chemical formula	C ₂ H ₈	C ₄ H ₁₀	CH ₄	C ₈ H ₁₇
Molecular mass	44	58	16	114

Density of the liquid phase at a temperature of 15°C and atmospheric pressure, kgm/m3	510	580	gaza 0.714	730
Boiling point at atmospheric pressure, °C	-43	-0.5	-161.6	>35
Heat of combustion in gaseous state, MJ/m3	85	111	50.08	213
Flammability limits when mixed with air under normal atmospheric conditions, % volume: lower/upper	2.4 / 9.5	1.8 / 8.5	5.0 / 15.0	1.5 / 6.0
Octane number	110	95	120	92
Compression ratio	10 – 12	7.5 – 8.5	–	8.2
Theoretically required amount of air for combustion of 1 kg of fuel, kg	15.8	15.6	–	14.7

Among all the gas fuels considered, methane gas can be considered the most efficient and environmentally friendly. Price analysis gives a ratio of 1.0.5:0.3, where gasoline is 1 and methane is 0.3. This means that for long-distance transportation and at high capacities, methane is most beneficial from all points of view. Harmful and dangerous emissions of waste methane are five times less than when operating a gasoline engine. During traffic accidents, methane will evaporate much faster and will not allow a fire to occur. But oil gas has a high density and can accumulate and become explosive [5]. In addition, in the concentration in which methane and air are present, at the point where the gas main breaks, it is simply impossible for the mixture to ignite.

There are, of course, negative factors of using gas fuel, but they in no way outweigh the advantages.

Methane is measured not in liters, but in cubic meters. The ratio of methane consumption compared to gasoline is 1 m³ of gas to 1 liter of gasoline, but with less power. This reduction in power is due to the following conditions:

1. Larger stoichiometric ratio with air and, as a result, less filling of the cylinders with the gas-air mixture.
2. Insufficient compression ratio; for gas it should be higher.
3. Longer combustion of the gas-air mixture due to a higher octane number.
4. Large additional weight of methane cylinders.

There are gas engines with spark ignition and with ignition of the mixture by pilot liquid fuel (gas diesel). Almost every car manufacturer already offers models that run on mixed fuel: gasoline/methane. Their diversity is becoming greater and greater.

The ability to choose from two types of fuel allows you to select the optimal mode. The choice depends, for example, on the weather. Thus, a gasoline engine performs better quickly during cold weather. Therefore, it is logical to start on gasoline and then switch to running on gas.

At the same time, if we take into account the vast territories of Kazakhstan and the agricultural orientation of the industry, it is necessary to solve the problem of transition to the efficient use of biofuel - biogas.

2 Material and methods

Materials for the study were, to a large extent, found on the Internet and in basic textbooks on materials science. A statistical analysis of data from surveys of motor transport enterprises

and service stations was also carried out. In addition, the authors have their own developments and articles on the issue of energy saving in transport and recycling. Also, Associate Professor Kasymzhanova K. and Associate Professor Mukhamadeeva R. were participants in research work on the development of technology for producing biogas [6].

The scientific novelty of the study lies in the fact that results were obtained confirming the possibility of using biogas to operate an internal combustion engine. Biogas is the most accessible and inexpensive gas in the agricultural sector of Kazakhstan. The practical significance of the work is a study of existing gas fuels and recommendations for improvement.

As for diesel engines, they are quite often used in luxury passenger cars, but mainly in all agricultural machinery and trucks. In general, we can assume that diesel is popular and in demand. According to international standards, fairly stringent requirements are imposed on diesel fuel, this is due to the fact that emissions contain sulfur. When burning fuel, the most dangerous are sulfur oxides.

3 Significance of the study

Diesel fuel emissions include the following components:

Carbon dioxide: Diesel engines, like all internal combustion engines, produce carbon dioxide, which is the main gas responsible for global warming.

Carbon monoxide: When diesel fuel burns incompletely, carbon monoxide is produced. It is a toxic gas that can cause heart and lung disease when in high concentrations in the atmosphere.

Nitrogen oxides: Oxidative combustion of diesel fuel produces nitrogen oxides, which are a major source of air pollution and play an important role in the formation of photochemical smog.

Particles: Diesel engines emit small particulate matter, or aerosols, consisting of soot, metals and other chemicals into the atmosphere. These particles can cause serious health problems, especially in children and people with chronic lung disease.

Harmful Organic Substances: Diesel fuel contains various organic compounds that may be released into the atmosphere in the form of vapors or particles. Some of these substances are carcinogenic and can cause serious illness.

Efforts are being made by automakers and governments to reduce diesel emissions, including developing more efficient engines, using filters to reduce particle emissions, and introducing alternative fuels such as biodiesel and electric vehicles.

Automakers, governments and environmental groups have recognized diesel engines as "green" engines due to their improved fuel economy and lower CO₂ emissions. Vehicles that are less fuel efficient and produce more CO₂ emissions are now subject to higher fuel tax, while diesel vehicles with the lowest CO₂ emissions are exempt from vehicle tax and congestion charges. Insurance premiums also depend on the amount of CO₂ emissions.

The UK Government acknowledges that air pollution from all sources contributes to approximately 30,000 deaths each year in the UK alone. But health problems caused by diesel fumes cost the UK's National Health Service 10 times more than similar problems caused by petrol fumes, according to research. The World Health Organization has stated that diesel exhaust fumes cause cancer and are comparable in their effects to second-hand smoke.

Diesel engine emissions are most dangerous if they are concentrated in large cities and there is no easy access for cleaning. Increased taxes for such vehicles have already been developed and are being implemented, for example, in India. Exhaust gases from diesel use are carcinogens, which are included in the list of substances that affect the development of cancer. These are nitrogen oxides, soot containing polycyclic hydrocarbons.

Pollutant emissions are calculated using the formula:

$$G_i = 10^{-6} * \sum^n q_i * L_q * A_e * K_c * D, \quad t/year \quad (1)$$

where: G_i - mass of pollutant emission (t/year);

n is the number of groups of cars, determined by observation;

q_i - specific emission of the i -th pollutant by one car, g/km

D - number of working days per year;

L_q is the conditional mileage of one car per cycle (entry and exit) in the territory under consideration; takes into account the time of starting the engine, moving around the territory and working in the parking area;

A_e - operational number of cars in parking lots;

K_c is a coefficient that takes into account the influence of the vehicle's driving mode (speed).

The maximum emission of the i -th pollutant is determined by the formula:

$$M_i = 10^{-3} * \sum^n \frac{q_i * L_q * A_e * K_c}{t_B * 3,6}, g/sec \quad (2)$$

where: M_i - mass of pollutant emission (g/sec);

n, q_i, L_q, A_e, K_c - similar values given above according to formula (1);

t_B is the time of release or return of cars in hours (assumed equal to 1 hour).

Table 2. Average fuel consumption rates for vehicles when driving in city conditions

Type of vehicle	Average fuel consumption rates (liter per 100 km)
A car	12
Freight car	31
Bus	43
Diesel truck	33
Gas engine	14

Due to the fact that vehicle exhaust gases enter the lower layer of the atmosphere, harmful substances are practically in the human breathing zone. Once in the blood, CO acts on red blood cells - red blood cells, which lose their ability to transport oxygen. As a result, oxygen starvation occurs, which primarily affects the central nervous system. When inhaled, nitric oxide combines with water in the respiratory tract to form nitric and nitrous acid. As a result, not only irritation of the mucous membranes occurs, but also very serious diseases. It is believed that nitrogen oxides are 10 times more dangerous to the body than carbon monoxide. A typical representative of carcinogenic substances, i.e. substances that promote the occurrence of cancerous tumors is benzopyrene. The car is the source of changes in air temperature in cities. If 100 thousand cars are moving in a city at the same time, then this is equal to the effect produced by one million liters of hot water.

In the history of the oil and gas industry in Kazakhstan, there is a clear inequality of attention and investment between oil and gas, reports inbusiness.kz. The total share of the gas sector in the upstream segment of the oil and gas sector is only 11.3% of GDP, with the gas sector having the smallest share, Halyk Finance analysts note in their latest review [5].

Natural gas is the cleanest fuel from an environmental point of view. Modern energy-saving equipment allows you to burn gas with high efficiency and minimal emissions of harmful substances, including carbon dioxide, which causes the greenhouse effect.

The main component of natural gas (85...99%, depending on the field) is CH₄ methane. Due to this, natural gas has the lowest ratio of carbon and hydrogen atoms of all motor fuels known today ($C/H \gg 0.25$), with the exception of hydrogen ($C/H = 0$). As a result, an engine running on natural gas has on average 20...25% lower emissions of carbon-containing harmful components, including the greenhouse gas CO₂, per 1 kW/h of generated energy than an engine running on oil fuel.

For the same reason, in a gas engine there are no emissions of high-molecular hydrocarbons (including carcinogenic polyaromatics), which are much more toxic than methane (for example, many standards for limiting emissions of toxic components with exhaust gases separately standardize emissions of non-methane hydrocarbons) [9].

Natural gas has a higher lower flammability limit of the working mixture in terms of excess air coefficient (α) in comparison with liquid fuels of petroleum origin. This allows the gas engine to operate at higher values of α (up to $\alpha \approx 2$) than when using liquid petroleum fuels. Operating the engine at high α values can significantly reduce the maximum combustion temperature of the mixture, which is the main factor in the formation of nitrogen oxides NO_x. The lower flammability limit of methane is significantly greater than that of gasoline, which makes it possible to implement the "lean combustion" concept, that is, operating the engine on lean mixtures in most modes. This, in turn, makes it possible to achieve low emissions of nitrogen oxides NO_x, as well as partially realize the benefits of high-quality engine power control.

All of the above allows the gas engine to meet stringent environmental requirements for NO_x emissions [7].

Due to the gaseous state of the fuel, a gas engine does not have the problems of homogenization of the air-fuel mixture inherent in engines running on liquid fuels. This means more complete fuel combustion, a significant reduction in CO and CH emissions, and virtually no emissions of particulate matter. In addition, the gas engine has lower CH emissions during cold start.

From an environmental safety point of view, the storage and transportation of natural gas is much safer than the storage and transportation of liquid fuels. Methane, the main component of LNG, is much lighter than air, therefore, unlike liquid fuels, when leaking from tanks and pipelines, it dissolves in the atmosphere without polluting the soil, reservoirs and groundwater.

A gas engine is quieter than an equivalent diesel engine (by an average of 10 dB), so converting diesels to gas engines makes a positive contribution to reducing noise levels in cities.

The exhaust gases of KAMAZ vehicles whose engines run on natural gas contain less carbon dioxide and carbon monoxide, respectively, by 25% and 80%. The absence of substances such as sulfur, soot and lead in exhaust gases is considered one of the most important advantages of methane as a fuel.

In general, exhaust gases from methane engines are almost 60% less harmful to human health, and they actually do not contain carcinogenic substances. KAMAZ engines operating on methane help reduce many adverse and dangerous phenomena. Among these are: acid rain, smog and the greenhouse effect [8].

Recognizing the facts above, most governments around the world are implementing programs to expand the use of natural gas as a fuel for road transport to meet environmental sustenance requirements.

In Europe, cars are allowed to emit 130 g/km of CO₂ (line average for each manufacturer). The norm was in effect until 2015, and by 2020 the threshold will be reduced

to 95 g/km. However, the role of the state is not limited to just introducing stricter environmental standards. It should encourage citizens to buy new cars that emit significantly less harmful gases.

There are standards for manufactured cars. European countries have adopted EURO standards that specify both toxicity and quantitative indicators, for example:

- According to Euro-3 emissions: CH up to 0.2 g/km, CO up to 2.3 g/km and NO_y up to 0.15 g/km;
- According to Euro-4 emissions: CH up to 0.1 g/km, CO up to 1.0 g/km and NO_y up to 0.08 g/km.

The gasoline internal combustion engine (GAE) is one of the most common types of engines used in the automotive industry. Despite its advantages, such as simplicity of design, high power and good controllability, BDVS has a number of disadvantages that should be taken into account when choosing a car.

Environmental Inefficiency: CVD burns gasoline, which is a non-renewable fuel and produces harmful substances such as nitrogen oxides, carbon dioxide and hydrocarbons, which are harmful to the environment and contribute to global warming.

Low efficiency: The combustion engine has relatively low efficiency because most of the energy released during fuel combustion is lost as heat and noise. As a result, CVD requires more fuel to produce a given level of power than other types of engines, such as diesel or electric.

High cost of maintenance: The MVD requires regular maintenance and replacement of parts such as spark plugs, combustion plugs and oil filters. This may result in increased operating and maintenance costs.

Possibility of Breakdown: The MDI has many moving parts that can wear out over time and cause failure. For example, pistons, valves, and the crankshaft may require replacement or repair if worn or damaged.

Fuel Dependency: The CVD is completely dependent on the availability of gasoline and cannot operate without it. If there is a shortage of fuel or its increased cost, a vehicle with BDIC may become unusable.

Sound Level: The RBD operates at a high sound frequency, which can be uncomfortable for the driver and passengers, especially at high speeds.

Health Effects: Emissions of harmful substances from airborne fuels can lead to air pollution and increased rates of respiratory diseases such as asthma and bronchitis.

Overall, although CVDs have their advantages, such as simple design and high power, they also have some disadvantages that should be considered when choosing a vehicle. These days, many car manufacturers are offering alternative engine technologies, such as hybrid and electric engines, which can provide cleaner and more fuel-efficient vehicle options.

Biogas is a renewable energy source that is produced by decomposing organic waste in the absence of oxygen. Biogas is used to produce electricity, heat and transport fuel, making it an important component in our quest for sustainable development. However, despite its advantages, the biogas production process faces a number of problems.

Uneven waste supply: Biogas is produced from organic waste such as food waste, manure and crop residues. However, the supply of such waste may be uneven, making sustainable biogas production difficult.

Lack of Efficiency: The process of breaking down organic waste into biogas may not be efficient due to various factors such as temperature, pH and nutrient content. This can lead to low biogas production rates and therefore reduced economic efficiency.

Environmental Pollution: Improper storage, transportation and handling of organic waste can lead to air, water and soil pollution. In addition, the use of biogas as fuel can result in emissions of greenhouse gases such as methane and carbon dioxide.

High equipment costs: The biogas production process requires specialized equipment such as biogas reactors, gas turbines and gas purification systems. This can lead to high initial investment and, in turn, make biogas production less competitive with traditional energy sources.

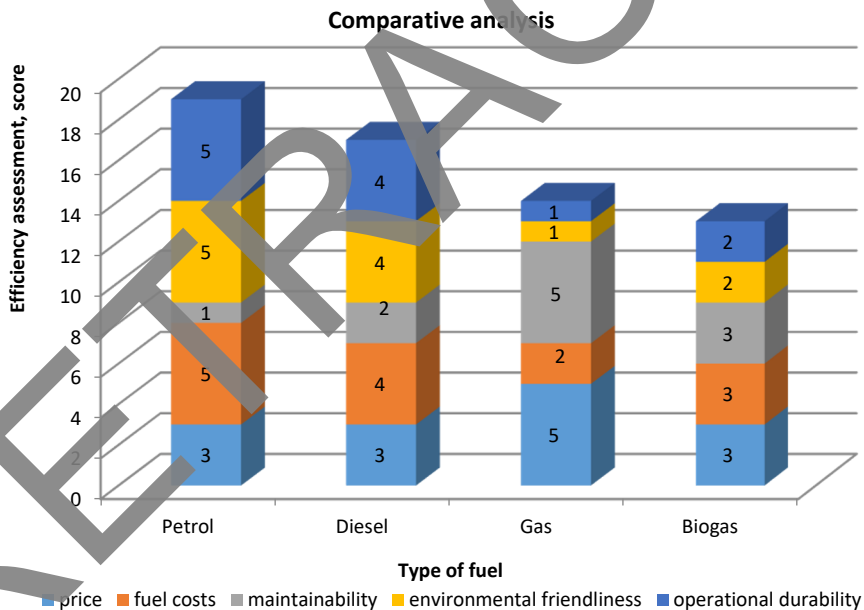
Limited quantity of waste: Although waste will always be generated, the quantity may be limited depending on the region and industry. This can lead to insufficient raw materials for biogas production, especially in large-scale industrial projects.

Lack of awareness: Despite its benefits, biogas is still not well known among the general public and investors. This may lead to insufficient funding and support for the development of biogas-related technologies.

Overall, while biogas is an important component in our quest for sustainable development, there are a number of challenges that need to be addressed to produce it more efficiently and at scale. This includes improving technology, ensuring a stable waste supply, reducing pollutant emissions and increasing awareness of the benefits of biogas.

Let's try to estimate the economic costs of operating vehicles using various types of fuel using the five-belt system. We choose the following as the main cost factors:

- the cost of the engine and average vehicle;
- fuel costs during operation;
- possibility of repair and routine maintenance;
- the amount of fines for violation of environmental standards;
- operational durability of the engine (mileage from refueling to refueling).



Note – compiled by the author [4]

Fig. 2. Comparative analysis of economic costs of various types of engines

The result of the comparative analysis (Fig. 2) based on average estimates demonstrates the advantage of vehicles with combined engines. It is necessary to clarify that this situation cannot be permanent and economic feasibility is justified for a separately selected northern region of Kazakhstan. Installation of gas-cylinder equipment in the nearest Russian cities is much cheaper, and due to low temperatures in winter, a complete transition to gas fuel is not advisable.

The operation of an internal combustion engine on gas motor fuel can significantly reduce the toxicity of exhaust gases, which is one of the reserves for improving the environmental situation on the roads. In addition, this allows you to reduce wear on the cylinder-piston group, increase the mileage between engine oil changes, extend the service life of spark plugs and exhaust system parts, and reduce fuel costs [10, 11].

4 Results

Biomethane combines all the positive environmental characteristics of gas fuel and does not have the disadvantages of gasoline fuel. As mentioned above, the service life of a car engine almost doubles. At the same time, the total mileage of the vehicle increases. Gas engine fuel has less toxicity than equipment running on liquid fuel. It has been absolutely proven that there are no solid particles in the exhaust gases, which means the fuel burns absolutely completely. There are no CH emissions when parked with the engine running. Therefore, we can put this criterion in first place among the reasons for switching to biomethane - no need to use expensive oil. Oil is not unlimited and its production is very harmful to the entire planet as a whole.

The second reason for the need to switch to biomethane can be stated as the problem of recycling organic waste. Instead of harming nature, help will be provided. This is not just clearing land from landfills, but also benefits the cycle. In practice, it's like the work of a perpetual motion machine, generating energy from nothing.

The third reason is availability and the possibility of production on an industrial scale and in large volumes. And at the same time the possibility of obtaining biogas at small enterprises, such as livestock farms, poultry farms, etc.).

And of course low cost with sufficiently large vehicle capacities. The conversion of gasoline engines to gas engines has already been mastered and is not particularly difficult, which means it is becoming accessible to all segments of the population in Kazakhstan.

5 Conflict of interests

There are opponents to the promotion of biogas, who suggest that there may not be enough agricultural land for crops. Statistics show that every day more than twenty thousand people die from hunger in the world due to lack of bread. If we talk about Kazakhstan, with a total population of twenty million, we have a population density of 8 people per square kilometer. This means there can be no talk of any conflict of interest. And it can even be assumed that biofuel can become a source for the release of a completely new type of automobile fuel - hydrogen [16].

Today there is already a need to develop and improve technology for producing biogas not from renewable raw materials and plant materials, but from recycled products. In this case, the problem of recycling and reducing landfills of solid household waste and food waste from public catering will be solved in parallel.

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