Analysis of alternative motor-vehicle fuels

M A Kovaleva1,2,4, V G Shram1, T N Vinichenko1,2, E G Kravtsova1, D G Slashchin1,2 and T Y Matkerimov3

1 Siberian Federal University, Krasnoyarsk, 660041, Russia
2 Reshetnev Siberian State University of Science and Technology, 660037, Russia
3 Kyrgyz State Technical University, Bishkek, 720044, Kyrgyzstan
4 E-mail: Lera0727@yandex.ru

Abstract. In this paper, the analysis of alternative fuels is carried out: electricity, hydrogen, biofuels (bioethanol, biodiesel, biogas), solar energy, compressed air, gas engine fuel (compressed natural gas, liquefied petroleum gas, liquefied natural gas). The advantages and disadvantages of their use are indicated according to the criteria of environmental safety, cost, and infrastructure development. It is revealed that at the moment, gas-engine fuel, in particular liquefied petroleum gas and compressed natural gas, is most suitable for the transfer of the fleet. The economic and environmental effect of the market expansion is associated with the high environmental friendliness of this type of fuel, low price, large natural reserves, the development of the petrochemical industry of the country, the reduction of financial costs for the repair and reconstruction of physically and morally outdated oil refining and liquid fuel production enterprises, promising technical and technological solutions to transport problems.

At the beginning of the 21st century the problem of accelerated motorization began to worry the world public. Reasons for this are high level of oil consumption as fuel (gasoline, diesel) for transport and the enormous environmental damage caused by the same transport.

It is an undeniable fact that road transport will remain the main mode of personal transport for a very long time. As of 1 January 2019, the vehicle fleet in Russia is 51.8 million units, 84% of which are passenger cars (43.5 million units), 8% are light commercial vehicles (4.1 million units), 7% are freight vehicles (3.8 million units) and about 1% for the bus fleet (0.4 million units). Gasoline and diesel vehicles account for about 90% of the total vehicle fleet in our country.

Oil is considered a non-renewable energy source and its reserves are gradually being depleted while oil consumption in our country averages 4 million barrels per day of which about 43 per cent of total consumption is transport [1].

Based on all of the above, the issue of alternative fuels in our country is becoming increasingly relevant.

In order to determine the most appropriate alternative to gasoline and diesel fuels for our country it is necessary to review and analyse the current alternative fuels.

At this point the following fuel types should be distinguished: electricity, hydrogen, biofuels (bioethanol, biodiesel, and biogas), and compressed air, solar energy, NGV (natural gas vehicle) fuel, liquefied petroleum gas (LPG), compressed natural gas (CNG) and liquefied natural gas (LNG).

Electric power. The history of an electric car is earlier than the emergence of an internal combustion
engine. But progress has slowed considerably because of the impossibility of producing heavy and more compacted batteries. However, at present, mainly due to Tesla, the electric car has become one of the main contenders for the replacement of traditional liquid fuels.

The efficiency of the electric car is several times higher than a car equipped with an internal combustion engine as indicated by the US Department of Energy study [2]. According to this study only 12-20% of the energy does get to the wheels in the city while in the case of the electric car the indicator ranges from 86 to 94%.

The electricity pricing is also significantly lower than the price of gasoline fuel. Charging costs depend on the electricity tariff. The full charge of the Tesla Model X 100D will cost from 200 to 600 rubles in the case of at-home charging (from 35 to 106 rubles for 100 km of driving) which is much lower than refueling a full tank of an average passenger car.

However, despite the advantages of using electric vehicles there are also disadvantages. So the speed of "charging" the car even at the modern Tesla Supercharger charging station from scratch reaches 75 minutes. Even considering that the electric vehicle does not produce gas emissions their use is not called environmentally friendly. Manufacture of automobile accumulators is far from harmless (toxins and fine dust are released during the production process), and their recycling is even more problematic because the batteries contain hazardous chemicals. For our country transition to electric vehicles in the near future seems completely impossible due to the lack of infrastructure. Outside the Moscow region and Saint Petersburg, the number of charging stations is minimal.

Hydrogen. Modern hydrogen cars are designed in two types. In the first case, hydrogen is used to generate electricity that is then used to power the electric motor. Thus, the vehicle uses a fuel cell to generate its own electricity. This technology is used in Honda FCX Clarity car.

In the second case, hydrogen is used instead of the conventional fuel in the internal combustion engine designed for this purpose. Instead of the harmful emissions produced by gasoline, hydrogen cars produce only water vapour. A noteworthy example is currently BMW Hydrogen 7. BMW leased several prototypes of cars in Germany and the United States. And then the tests showed that the car cleaned the air around it while it was driving.

But the hydrogen car has significant downsides. So it’s extremely expensive to produce hydrogen on an industrial scale using water electrolysis. Given the explosive risk of hydrogen in contact with oxygen there are no standards for the storage, transport and use of hydrogen as a fuel. The lack of infrastructure for refueling the hydrogen vehicles also plays a significant role [3].

Biofuel. Biofuel is a fuel from renewable raw materials. Let's look at some types of existing biofuels. Bioethanol is a common ethanol obtained in the process of raw materials processing. It is a biofuel substitute for gasoline produced mainly from cereals.

Fuel ethanol is neutral in terms of greenhouse gas emissions. The oxygen contained in bioethanol contributes to more complete fuel combustion. The presence of only 10% ethanol in petrol reduces carbon monoxide emissions by 30%. The drawback of bioethanol is that one third less energy is released from combustion of a liter of this fuel than from combustion of the same volume of gasoline.

Biodiesel is a substitute for diesel. It is produced from grain oils (most commonly palm oil or rapeseed). This fuel does not contain sulfur in its composition unlike diesel fuel. The use of biofuels does not reduce engine life, but significantly reduces harmful substances emissions (by 25-50%). Equally important is that, in the event of an accident biodiesel would not harm plants and animals.

The drawback of such fuel is its increased aggressiveness to car rubber parts and paint coating of the body, as well as the increased release of nitrogen oxide compared to conventional diesel fuel. The high cost of this fuel should also be taken into account. In our country biofuels are subject to excise tax which in turn increases the price of the fuel itself.

Biogas is a biofuel substitute for natural gas. Biogas is obtained from organic waste and debris that have undergone methane fermentation. Agricultural liquid and solid wastes, sewage and manure can be used to generate biogas. The disadvantage of biogas is its widespread availability only in rural areas, which are rich in raw materials for production, as well as in industrial scale production [4].
Compressed air. The vehicle using compressed air as fuel the air is compressed in high pressure pipes. The compressed air engine unlike an internal combustion engine using liquid fuel air uses the expansion of compressed air supplied from a high-pressure pipe to drive the engine pistons.

Anyway, compressed-air cars don’t work on it completely. There is also an electric motor on board that is designed to compress air and sends it to high-pressure pipes. But unlike electric cars the electric motor does not participate fully in the power of the car driving the wheels. These engines occupy much less space and consume less energy than electric vehicles. Due to this, charging a car running on compressed air is much faster than charging an electric car.

Unfortunately, despite the total environmental friendliness of this transport and the low cost of fuel, such a vehicle has significant disadvantages. So the pneumatic engine has a small efficiency factor compared to the internal combustion engine. Also, due to the low power output per unit of capacity, all compressed-air vehicle performance is well below that of conventional fuel vehicles. In addition, the production of compressed-air vehicles is only at an early stage of development. Current examples include Airpod and Airpod 2.0 3-wheeled pneumatic car (the French company Motor Development International) and miniCAT pneumatic car developed by the Indian company Tata Motors [5].

Solar energy. The cars using solar panels as a source of energy or as they are called «solar cars» have appeared relatively recently. The operation principle of this vehicle is the conversion of solar energy into an electric power source, which is a source of power for the electric motor installed in the vehicle. Most of the existing power generation systems accumulate in batteries, from which the electric motor is driven, which in turn rotates the wheel.

The advantages of this vehicle include: no emissions of pollutants into the atmosphere (not including the production and recycling of batteries); practically unlimited supply of energy source (sun); no charging is required at special stations as opposed to conventional electric vehicles; free energy for car operation and long service life.

The disadvantages of the «solar cars» include: low-volume production, as well as the use of new technologies which leads to the high cost of the car; dependence of this type of transport on terrain and weather; low performance compared to conventional vehicles (drive range, driving speed); total lack of car service centers for this transport which complicates its operation [6].

NGV (natural gas vehicle) fuel. There are three varieties of NGV fuel: compressed natural gas (CNG), liquefied petroleum gas (LPG), liquefied natural gas (LNG).

Compressed natural gas (CNG) is methane natural gas compressed in compressor units up to 200 atm.

The rationale for using CNG as a substitute for conventional fuel:

- CNG has a high octane number (110-125) which practically eliminates knocking and reduces the load on engine parts;
- CNG does not form sediments in the fuel system; it does not wash the oil film from the cylinder walls, thus reducing friction and engine wear. Methane combustion does not produce the particulates and ashes that cause increased wear on the cylinders and pistons of the engine. Thus, the use of CNG as a fuel increases the engine life by a factor of 1.5-2;
- The concentration and temperature limits of CNG ignition are significantly higher than for petrol and diesel. Methane is twice as lighter than air and dissolves rapidly in the atmosphere when leaked;
- CNG costs significantly less than gasoline and diesel fuel. The average retail price of CNG in Russia is 16 rubles per 1 m3 (which in terms of its energy properties is approximately 1.2 liters of petrol) against 45.57 rubles/l (price for 14.06.2019) of the most popular gasoline AI-95 in our country;
- The environmental factor is also significant. When natural gas is used instead of conventional fuel, the release of toxic substances into the environment is approximately 10 times less for
carbon monoxide, twice less for nitrogen oxides, three to five times less for hydrocarbons, nine times less for smoke, and there is no soot associated with diesel engines.

But CNG, in turn, has significant disadvantages that severely limit its use as fuel for passenger transport. For example, when using methane, the performance of a car is significantly lower than that of a conventional vehicle (about 20%). Due to methane compression, storing requires strong, thick-walled cylinders, sometimes up to 100 kg. A tank of this size could stretch 250 kilometers. An important fact for motorists is that methane-powered gas-cylinder equipment will generally be much more expensive to install. There are already lighter metal plastics or polymer composite cylinders, but due to the complexity of installation and the price above the price of already expensive metal cylinders, they are not developed in our country. The downside is also the number of Automobile CNG Filling Stations in our country, which leaves much to be desired. But for the sake of justice it is worth to say that «Gazprom» makes a big bet on compressed natural gas (CNG) in the future and plans to expand gas-filling infrastructure.

Liquefied petroleum gas (LPG) is a mixture of butane and propane in various proportions obtained in gas processing plants after fractional distillation of the petroleum associated gas. The propane-butane mixture has a high critical temperature and can therefore be stored and supplied to the consumer in a liquefied state at a temperature of minus 40 to 45 °C and a pressure of 1.6 MPa or 16 atm. The octane number of the propane-butane mixture varies between 102 and 112.

The same reasoning as for liquefied petroleum gas (LPG) is valid for the use of compressed natural gas (CNG) as fuel. Except that the propane-butane mixture is a less environmentally friendly fuel than methane, but at the same time it is ahead of gasoline and diesel in this parameter. When using LPG as a fuel, the emission of harmful substances is reduced by 2–3 times for carbon monoxide, 1.2 times for nitrogen oxides, and 1.9 times less for hydrocarbons. When using LPG as a fuel, the emission of harmful substances is reduced by 2–3 times for carbon monoxide, 1.2 times for nitrogen oxides, and 1.9 times less for hydrocarbons. In the case of mega-cities, even a small difference in the environmental performance of fuels will play a significant role. The average retail price of LPG in Russia as of June 10, 2019 is 22.66 rubles per liter, which is 2 times cheaper than the price of AI-95.

The main advantage of LPG over CNG is that compressed natural gas equipment (CNGE) for the propane-butane mixture takes up much less space, has less weight, and its installation is much easier and cheaper.

The disadvantages of LPG include an increase in fuel consumption compared to gasoline by 10-20%. The use of LPG is limited by gasoline engines due to the instability of combustion at a high compression ratio in diesel engines. On top of that, propane butane is 1.5-2 times heavier than air due to which the leak accumulates near the ground, creating an explosive and unhealthy atmosphere. Therefore, vehicles with compressed natural gas equipment (CNGE) are stored in open parking areas and repair areas are provided with good ventilation.

Liquefied natural gas (LNG) is methane cooled to a condensation temperature (minus 161.5 °C) at which it is converted to a liquid state. The gas volume is reduced by 600 times. The key consumers of LNG in the future are considered to be railway, water transport, and mining and agricultural machinery. The advantages of such fuel are as follows:

- Fuel costs for the use of LNG are 30-50% lower than for petrol and diesel.
- Emissions of pollutants to the atmosphere from the use of liquefied methane are significantly lower: there are no solid particles and sulphur compounds, emissions of carbon monoxide and heavy hydrocarbons are reduced to 65% and emissions of nitrogen oxides are reduced.
- The use of LNG as a motor fuel extends the engine life by a factor of 1.5. This is due to the fact that natural gas during combustion does not form sediments in the engine and does not wash the oil film from the cylinder walls, reducing friction and engine wear. During engine operation no detonation occurs in the cylinders, which significantly reduces the load on the elements and units of the cylinder-piston group.

Disadvantages include the current lack of infrastructure in our country to use LNG as a fuel. But it
is worth mentioning that the development of LNG as NGV fuel is one of the priority tasks of «GAZPROM GAS MOTOR FUEL» LTD today [7, 8, 9].

Today, natural gas is the most economical, environmentally friendly and safe fuel. Natural gas is actually a ready-made motor fuel, so it is much cheaper than gasoline and diesel fuel. At the same time, the engine of such a vehicle meets the highest standards—Euro-5 and Euro-6. According to the classification of the Ministry of Emergency Situations, natural gas belongs to the safest class of combustible substances. The annual savings for the projected model is 20488.05 rubles. Based on this, we can say that it is more economical to use a converted car for gas in terms of the financial component. The presented indicators for the basic and projected versions are shown in figure 1.

It can be concluded that the transfer of road transport from oil fuels to gas has many advantages. The operating costs for the year in the basic version practically do not differ from the projected one. The cost of HBO and its installation pays off in 2 years, and there will also be a noticeable benefit in fuel costs.

Based on the analysis and comparison of alternative fuels, it is clear that NGV fuel, in particular LPG and CNG, are the most suitable for the vehicle fleet transfer at this time. LPG fuel would be an excellent transitional option for passenger cars, and the CNG fuel is already widely used in trucks and buses.

Both specific companies and the state are interested in the development of the gas engine fuel market. This allows us to hope that the current wave of development of transport infrastructure and transport will be successful and will solve many environmental problems.

References
[1] Information on https: / / www.autostat.EN /
[2] Information on https: //https://fueleconomy.gov/feg/atv-ev.shtml
[3] Shayakhmetov A B 2017 Science and technology of Kazakhstan 4 106-15
[4] Moskvin P A 2011 SPbPU Scientific and Technical Bulletin Natural and engineering sciences 2 269-74
[5] Skorenko T Yu 2014 Popular mechanics 12 102-6
[6] Zarirov R Yu 2017 Science and technology of Kazakhstan 3 36-45
[7] Bezborodov Yu N, Kovalova M A, Sokolnikov A N and Shram V G and Tsygankova E V 2019 IOP Conf. Series: Materials Science and Engineering 537 062019
[8] Kostyukov V U 2017 *Sphere Oil and gas* 2 58-66

[9] Bezborodov Yu N, Kovaleva M A, Sokolnikov A N, Shram V G, Lysyannikova N N and Karkashenko A O 2019 *Journal of Physics: Conference Series* 1399 055008