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STUDY OF THE ROLE OF ALTERNATIVE FUELS IN THE ENERGY BALANCE OF UKRAINE AND THE COUNTRIES OF THE EUROPEAN UNION DURING ARMED AGGRESSION AND IN THE POST-WAR RECONSTRUCTION OF THE COUNTRY'S ECONOMY AND INFRASTRUCTURE

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Abstract

In the article, which shows the results of the authors' own research, the purpose of which was to identify the quantitative and qualitative aspects of the role of alternative fuels in the energy balance of Ukraine and the countries of the European Union during the times of armed aggression and in the post-war reconstruction of the country's economy and infrastructure, the following tasks were consistently solved: analysis of the consumption of energy resources in the world and in Ukraine and the use of alternative types of fuel in transport; analysis of the nomenclature and properties of fuels of non-petroleum origin. The object of the study is the role of alternative fuels in the energy balance of Ukraine and the countries of the European Union. The subject of the study is quantitative and qualitative aspects of the object of the study at the time of armed aggression and in the post-war reconstruction of the country's economy and infrastructure. The scientific novelty of the research results is that the notion of the applicability of various types of alternative motor fuels for powering the power plants with reciprocating internal combustion engines, in particular the FERV units of the units of the SES of Ukraine, has gained further development, in terms of their solving problems both during the times of armed aggression and during the period of post-war reconstruction of the country's economy and infrastructure. The practical significance of the research results is that the the results of a comparative analysis of the nomenclature, properties and prospects for the use of various types of alternative motor fuels for powering power plants with reciprocating internal combustion engines are suitable for use in the developing of strategic foundations for the functioning of the fire and emergency-rescue vehicles units of departments of the State Emergency Servise of Ukraine during armed aggression and during the period of post-war reconstruction of the country's economy and infrastructure.

Key words: traditional motor fuels, alternative motor fuels, biodiesel, benzoethanole, hydrogen, environmental protection technologies, ecological safety, power plants, reciprocating internal combustion engines, fire and rescue vehicles, armed aggression, post war reconstruction.

Statement of the problem and analysis of the sources

The growth of industrial production in the world has led to a significant increase in the consumption of fuel of petroleum origin. Over the past 25 years, this component in the overall world energy balance has increased by 4.2 times or by 68 % and is estimated at 3 billion tons per year [1–5].

As a result, a number of countries began to experience a shortage of traditional types of fuel, mainly such universal and convenient as oil, which intensified the search for a substitute (full or partial) fuel of petroleum origin.

Solving the problem of significantly reducing the consumption of motor fuels by improving the operating cycle of the power plants (PP) with reciprocating internal combustion engines (RICE), including the units of fire and emergency-rescue vehicles (FERV) of departments of State Emergency Service of Ukraine (SES of Ukraine), installed on them is hardly achievable. This is due to the fact that there are known ways to increase efficiency, such as: improving the fuel system and ignition systems, including the use of microprocessor systems for fuel consumption management; turning off part of the cylinders and cycles; layer-by-layer fuel-air mixing; gas exchange process management; supercharging of engines; exhaust gas recirculation is not effective enough to radically solve the problem.

The most effective way in this case is the use of renewable energy sources, fuels of biological origin (FBO) and their mixture with traditional ones. Alcohols (ethanol, methanol), vegetable oils (rapeseed, sunflower, soybean, etc.) and their esters, generator gas, biogas, and other combustible gases belong to the FBO. Biomass, which is the products and wastes of agricultural and other types of production, is the raw material for producing FBO. Ukraine has significant amounts of such raw materials [1–5].

The following main methods of obtaining energy from biomass are known: direct combustion, thermochemical methods (gasification, pyrolysis), biological method (anaerobic fermentation). These methods are widely used: the first two are for the processing of agricultural plants, livestock waste and wood processing, the third is for the processing of livestock waste.

To date, the most cost-effective technologies for generating electricity from biomass are considered to be mini PP that operate on gas obtained from landfill material, i.e. solid waste landfills.

Among the decisions of the first Ukrainian disciplinary conference «Energy from Biomass» (November 23–26, 2002, Institute of Technical

Thermophysics of the National Academy of Sciences of Ukraine (NAS of Ukraine) and National Research Center «Biomass»), it was stated that in the near future the following technologies and equipment would be the most promising for use in Ukraine [5]:

– wood burning stations for centralized heat supply and industrial boilers operating on wood of woodworking plants;

– boilers for burning straw on farms;

– boilers for burning wood and straw of low power (40…100 kW);

– biogas plants for cattle farms, pig farms, poultry farms and food industry enterprises;

– installations for extraction and processing of biogas from large waste dumps and domestic sewage treatment plants;

– technologies for joint combustion of biomass with coal at existing PP;

– production of motor fuel from biomass.

Time has shown that the outlined directions have still not lost their relevance, and the last one has only increased it, since the need for motor fuel for our country is currently very acute.

According to the National Energy Program of Ukraine for the period until 2020, it was expected to cover 10 % of the national economy's energy needs with the help of non-traditional and renewable energy sources.

According to experts' forecasts, the production of FBO in Europe will triple in the coming years compared to the current level. The increase in demand for this fuel in the region is stimulated by the legislative decision adopted by the European Commission on the mandatory inclusion by 2020 of bioethanol in gasoline in the amount of 5.75 % by oil companies of the member states of the European Union (EU). The demand for it will continue to grow, as there is a goal to bring this indicator in the EU to 8 % in 2015 and expected to 20 % in 2020 [6(1)].

In Brazil and the United States, a fuel called «gasohol» is widespread, which is a mixture of 80 % gasoline and 20 % ethanol (Brazil) or 90 % gasoline and 10 % ethanol (USA). More than 50 % of transport in Brazil runs on ethanol and its mixtures with gasoline. This was facilitated by the supply to Brazil by the Volkswagen concern of a large number of cars with engines adapted to work on fuels containing alcohol.

Sweden's experience in the use of benzoethanol fuels is represented by the composite fuel E-85, which contains 15 % gasoline. Alcohol is produced here from wood, and new technologies of two-stage hydrolysis make it possible to obtain 250 liters of alcohol from each ton of pulp.

The leading foreign countries show no less interest in the use of alcohol fuels in diesel engines. An example can be the use in Germany and France of biofuel from technical rape under the names «biodiesel» and “diester”, respectively.

In the USA, Germany, Japan, France, Finland and other countries, research is being conducted on the use of fuel based on a mixture of bioethanol with diesel fuel in diesel engines. It is necessary to solve the issue of corrosion resistance of the fuel equipment, improve the characteristics of the quality of the launch, the stability of the fuel mixture and increase its octane number, etc., therefore, relevant research is being conducted in these areas. Satisfactory results have already been obtained when using diesel mixtures with a content of 95 % ethyl alcohol in diesel fuel.

Based on the world experience in the production and use of FBO as motor fuels or additives to petroleum fuel, it can be stated that ethanol can be used at the first stage in Ukraine, and FBO based on rapeseed oil at the second. The raw material for ethanol is vegetable biomass. Its motor qualities are close to petroleum fuels, but it usually costs less than gasoline or diesel fuel.

Rapeseed oil is not used as a fuel in diesel engines due to unsatisfactory values of its individual characteristics. Therefore, it is either added to diesel fuel in various proportions, or processed into methyl or ethyl ether (in the latter case, there is practically no waste). Rapeseed oil processing products – glycerin and fodder meal are then used in other industries.

European fuel «biodiesel» is just methyl or ethyl ether of higher fatty acids of rapeseed oil. According to statistical data, in the countries of Central Europe, from 1.0 to 1.2 tons of biodiesel are obtained from 1 hectare of rapeseed.

Biogas obtained from solid waste landfills, from vegetable raw materials and livestock waste is a fairly effective fuel for RICE, but for its widespread use, the development of the appropriate infrastructure is necessary.

The choice of an alternative FBO for use in a specific area has been made after conducting an appropriate analysis of the resource base, economic and ecological feasibility of its production and use possibilities.

As of February 24, 2024, that is, before the start of a full-scale Russian invasion of Ukraine, Ukraine was one of the energy-dependent states: it supplied itself with only 24…25 % of gas and 12 % of oil from its own resources. Therefore, the use of FBO in the country appears to be a promising direction, the movement of which will not only save up to 20 % of oil fuel, but also improve the ecosafe state of environment due to the better ecological characteristics of diesel engines operating on FBO.

In Ukraine, there are real opportunities for the production of FBO, but according to experts, for their rapid introduction on the country's fuel market, the adoption of laws on the mandatory use of FBO as an additive to petroleum fuels or as independent fuels is necessary.

In the countries, which already have experience using FBO, there are proven technologies for adapting RICE to a specific type of fuel, ensuring its effective and safe use. Many technical solutions have been presented as “know-how”. However, as the results of tests of RICE on FBO in bench conditions and in the process of exploitation have shown, the reserves of improvement of existing technologies are far from exhausted and give the hope to obtain higher economic and ecological indicators of RICE adapted to FBO.

In Ukraine, there is still no mass using of FBO on PP with RICE, so the development of this direction is a relevant and urgent task.

The most important problem of Ukraine and the EU countries is the rational use of natural resource potential, primarily energy resources, while maintaining an economically acceptable level of ecological safety. Targeted energy saving activities are of particular importance. It will develop due to the growth of the potential of non-traditional energy, which uses secondary and renewable resources.

Currently, the largest consumer of fuel is PP based on RICE – both stationary and transport, operating mainly on traditional motor fuels. Meanwhile, there are large reserves of high-quality alternative fuel of non-petroleum origin (both natural and synthetic), which do not require any chemical processing for use in diesel engines. They include natural gas, hydrogen, as well as other promising unconventional fuels based on hydrocarbons and hydrogen (biogas, coke gas, blast furnace gas, generator gas, synthesis gas, etc.).

One of the important conditions for the successful use of alternative fuels (AF) as working bodies is the creation of modern engineering methods for calculating their vapor–liquid equilibrium and thermodynamic properties. These calculation methods must simultaneously satisfy such requirements as accuracy and the possibility of application in a wide range of pressures and temperatures while using a minimum of initial data.

Obviously, for practical purposes, direct experimental data on the properties of AF are better. However, it is difficult, and often even impossible, to determine the properties experimentally in a wide range of states. Thermophysical characteristics of AF are required in the intervals of states from combustion parameters (or pyrolysis of components) to the liquid state inclusively, including at cryogenic temperatures, and taking into account the huge spectrum of compositions of multicomponent AP. In addition, information on thermophysical properties should be suitable for use in current calculations, that is, be operational if necessary.

When considering the set of previously proposed methods for calculating the thermophysical characteristics and parameters of the phases equilibrium of the specified working bodies [1–6], two main approaches can be distinguished. The first consists in describing the properties of vapor and liquid with single (mostly empirical) equations of state. In the area of low and medium pressures, another approach is most common, in which the vapor and liquid phases are represented by fundamentally different models.

For the first and second approaches, a significant number of empirical equations of state with a large number of constants (model parameters) are proposed. Their use for liquid–vapor equilibrium calculations only gives acceptable results only for the range of temperatures, pressures and compositions for which the data were used in determining those parameters.

Based on the analysis of the state of the problem of describing phase equilibria, it was concluded that the results obtained within the framework of similar approaches and schemes are unsatisfactory in quantitative terms. At the same time, it should be taken into account that currently a more developed direction of research on increasing the level of ES in the process of exploitation of PP with RICE is the introduction of alternative motor fuels of biological origin, which requires a suitable criteria-based mathematical apparatus for a complex assessment of the obtained effect [6, 7]. Appropriate environmental protection technologies require the development of new and improvement of existing executive devices [8], as well as criteria for complex assessment of their functioning efficiency [9]. The ecological issues of disposal of combustible solid and liquid waste [10] and solid products of combustion of traditional fuels – coal and masute [11] should be highlighted separately.

The question of using hydrogen in modern diesel RICE in various aspects [31] and its production for this purpose [36] is an urgent trend, for example, the use of alternative motor fuel based on polyethylene plastic with hydrogen saturation [12], adding hydrogen to the combustible mixture in a traditional diesel motor fuel [13, 22, 23], with the addition of aromatic hydrocarbons and ethers [14] and products of animal husbandry waste processing and zirconium oxide nanoparticles [15], ethyls with multilayer carbon additives [16], plastic oil waste [34], biodiesel production waste and diesel fuel of degraded quality [24] in the combustible mixture of diesel RICE that uses hydrogen as a secondary fuel, the use of biodiesel fuel in combination with EG recirculation [17], the use of fuel ionization [26]. In addition, active research is being conducted on the use of hydrogen additives and in the combustible mixture of RICE with spark ignition [18], including with the addition of biogas and liquid biofuel [19,21] and bioethanol [32], with charge stratification [20] and with a homogeneous mixture [29], with the adjustment of spark ignition parameters [33] and valves of the gas distribution mechanism [35], with the addition of ammonium [25], working on a mixture of ethanol and hydrogen [27]. The use of hydrogen additives in the combustible mixture in various types of RICE also contributes to the reduction of greenhouse gas emissions [28]. The role of hydrogen as a fuel for RICE in small aviation is also considered promising [30].

This state of the problem determines the **relevance of the study** on the comparative analysis of sources of scientific and technical information regarding the study of quantitative and qualitative aspects of the role of alternative fuels in the energy balance of Ukraine and the countries of the EU during the times of armed aggression and in the post-war reconstruction of the country's economy and infrastructure, which is also relevant for ensuring effectiveness, alternativeness and reliability of the functioning of fire and emergency rescue equipment units of the departments of the State Emergency Service of Ukraine

The aim of the study. Identification of quantitative and qualitative aspects of the role of alternative fuels in the energy balance of Ukraine and the countries of the EU during the times of armed aggression and in the post-war reconstruction of the country's economy and infrastructure.

The object of the study. The role of alternative fuels in the energy balance of Ukraine and the countries of the EU.

The subject of the study. Quantitative and qualitative aspects of the object of the study at the time of armed aggression and in the post-war reconstruction of the country's economy and infrastructure.

During the implementation of this scientific research, the following **research methods** have been used: the analysis of scientific and technical, reference, normative, and patent literature.

The research objectives are as follows.

– analysis of the consumption of energy resources in the world and in Ukraine and the use of alternative types of fuel in transport;

– analysis of the nomenclature and properties of fuels of non-petroleum origin.

Analysis of the results of the conducted research allows us to highlight the following aspects of their **scientific novelty**. The notion of the applicability of various types of alternative motor fuels for powering the PP with RICE, in particular the FERV units of the units of the SES of Ukraine, has gained further development, in terms of their solving problems both during times of armed aggression and during the period of post-war reconstruction of the country's economy and infrastructure.

The results of the performed research can be of the following **practical use**. The results of a comparative analysis of the nomenclature, properties and prospects for the use of various types of alternative motor fuels for powering PP with RICE are suitable for use in the developing of strategic foundations for the functioning of the FERV units of departments of the SES of Ukraine during armed aggression and during the period of post-war reconstruction of the country's economy and infrastructure.

1 Analysis of the consumption of energy resources in the world and in Ukraine and the use of alternative types of fuel in transport

For many years, fossil fuels have been the primary choice when it comes to fueling thermal PP, the various types of heat engines used to generate energy. Perhaps, until the end of the 70s of the 20th century, there was no need to worry about the depletion of this fuel, about the environment, which was polluted by the products of hydrocarbon fuel combustion. The gradual increase in the rate of energy consumption, which is characteristic of the industrial stage of social development and is peculiar to the industrial stages of development, eventually led humanity to the need to solve the following main problems:

– restoration of energy resources;

– depletion of energy resources;

– cost effectiveness for attracting resources;

– neutralization of environmental consequences of development, recovery and use of energy resources.

The last problem in this list at the end of the 20th century and the beginning of the 21st century is a part of the global ecological problem and is interpreted by various researchers as a problem of sustainable development of mankind, ensuring the viability of civilization. An equally significant problem that needs to be fulfilled is the resource provision of the energy sector of the economy. In recent years, the world has been concerned about both environmental pollution and the possible rapid depletion of the usual natural fuel and energy resources.

The first decade of the 21st century is characterized by deep transformations in the world economy, which are unfolding against the background of the processes of globalization of the energy and ecological crisis. The materials of various energy forums, scientific conferences and publications are diverse and ambiguous, the forecasts for the near future and the perspective are often of subjective in nature. In this regard, in the study we will try to analyze the situation in the market of production and consumption of fuel and energy resources.

Energy resources are a stock of primary energy carriers that are available for extraction and use (both basic and those that are developed and potentially possible). The classification of primary energy carriers is based on schemes that differ in principle. According to one of these schemes, renewable and non-renewable, traditional and non-traditional energy carriers can be distinguished (Fig. 1 [5]).

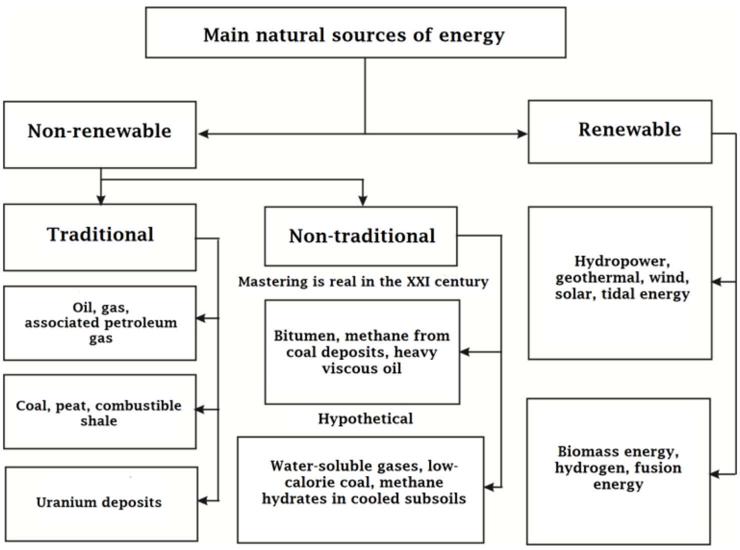

Figure 1 – Structure of primary energy carriers [5]

It is believed that the reserves of traditional gaseous and liquid carbohydrates are being depleted. As of 2008, the explored resources should be enough: oil – for 42 years, gas – for 60 years. Most authoritative forecasts agree that in the foreseeable future (before large-scale use of alternative sources of energy) non-renewable energy resources will be sufficient [37]. Forecasts of research centers, oil companies, and international organizations are usually based on information about known explored reserves of hydrocarbons and existing resource extraction technologies. The creation of new resource extraction technologies can significantly adjust forecasts in the direction of increasing the share of available resources.

In addition, the accuracy of the methods and criteria used to process the results often depends on general economic and political factors, market conditions. But, despite this, during the 20th century, according to [5], the consumption of commercial energy resources increased 15 times. From 1975 to 2005, it exceeded the amount of consumption for the entire previous period of human civilization and in 2005 reached 15 billion tons of conventional fuel per year. By the beginning of the 21st century, the share of oil in the world's total energy consumption was 40 %, coal – 27 %, gas – 23 %, atomic energy – 7 %, hydro, solar and wind energy – 3 %. The dynamics of energy distribution by its types in the 20th century [5] is shown in Fig. 2 [5].

In 100 years, the number of existing types of energy sources increased from two at the beginning of the 20th century to six at the end of the century. It is significant that none of the new sources has any tendency to reduce their production, on the contrary, they are gradually moving into the category of traditional ones, having a different share in the energy balance. The determination of this share in the future has been the subject of recent disputes among forecasting organizations. According to one such forecast of changes in the structure of energy consumption in the world (in oil equivalent) [5] by 2100, the share of coal begins to increase, and the use of traditional sources begins to decrease from 2020, as a result of replacement by bitumen and new sources of oil and gas (Fig. 3 [5]).

The share of natural gas remains large and almost unchanged. Its value is very large, especially in the countries that consume natural gas from external sources: Ukraine – 41 %, Germany, Spain – 24 % [37]. The use of innovative, alternative energy sources will increase significantly only from 2125, and their share may reach 50 % by 2100.

Another long-term forecast (Fig. 4 [5]) of the dynamics of growth and decline in global oil consumption until 2125 is proposed in [38], taking into account the consumption of petroleum products in the United States.

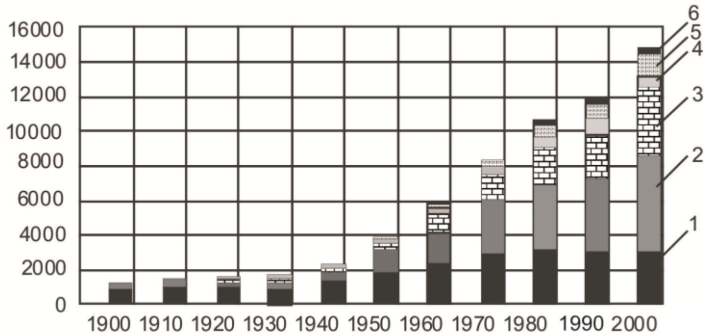

Figure 2 – Dynamics of the structure of energy consumption in the world in the 20th century [5]:
horizontal axis – date in years; vertical axis – level of consumption in million tons of conditional fuel;
1 – coal, oil shale, peat, firewood; 2 – oil and oil products; 3 – natural gas; 4 – hydro energy; 5 – nuclear energy;
6 – biomass, wind energy, geothermal energy and other

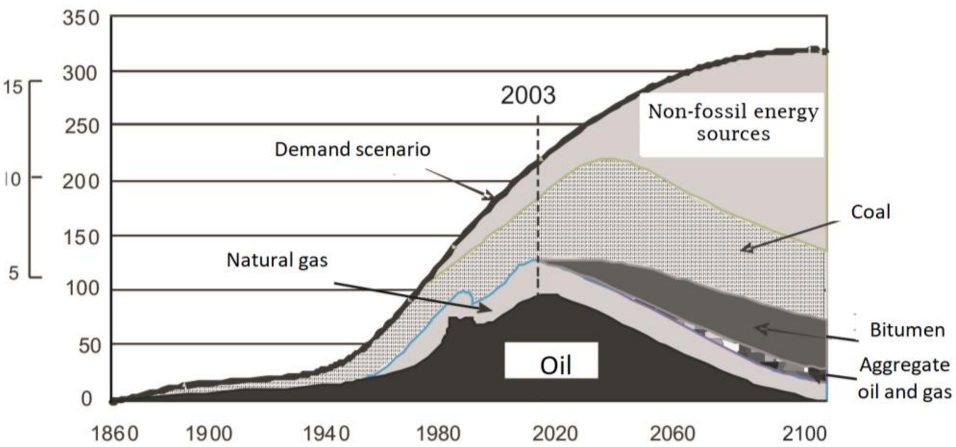

Figure 3 – Forecast of changes in the share of the main types of energy raw materials
in ensuring global energy consumption [5]:
horizontal axis – date in years; vertical axis – amount of energy consumption
in billion tons of conditional fuel per year and million of barrels per day in ratio 100 : 5

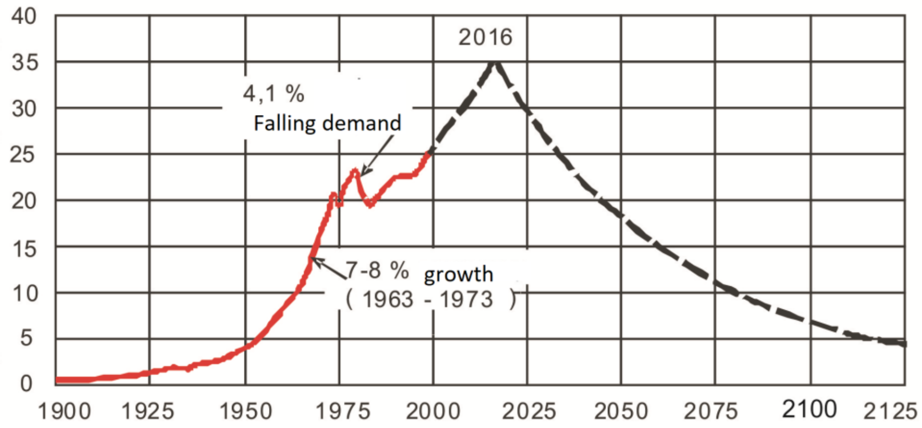

Figure 4 – Assessment of global oil consumption [5]:
red solid line – real annual consumption of oil; black dashed line – demand forecast with 2 % growth-fall:
horizontal axis – date in years; vertical axis – production of fuel in billion tons of conditional fuel per

The forecast was made in 2000, and at the moment it is a realistic assumption that peak consumption may shift in one direction or another due to fluctuations in oil prices and the global financial and economic crisis that began in 2008.

Deeper and more accurate estimates of the use of energy resources refer to shorter periods. In particular, the forecast of the US Energy Information Administration (USEIA) under the Ministry of Energy for the period until 2025 assumes that the global consumption of primary energy resources in 2010 will reach 16 billion tons of conditional fuel, in 2020 – almost 20 billion tons of conditional fuel, and in 2025 – about 22 billion tons of of conditional fuel (see Fig. 5 [5]). The average annual growth rate of energy consumption in the world during this period will be 1.9 %. At least values of 16 billion tons of conditional fuel may be checked soon.

The economy of energy consumption depends on many factors. An important aspect is the improvement of energy efficiency as a whole, which suggests to minimize the consumption of energy resources (or a primary resource, or any other transformed form of it) to obtain some useful effect, which is often expressed not in a direct reduction in the specific consumption of energy carriers, but in a significant diversification their consumption based on domestic ecologically safe technologies of consumption of non-renewable energy resources.

Extraction and supply to the market of millions of tons of fuel and energy raw materials is a complex process of transformation of a natural resource into a commercial product, which is accompanied by the mobilization of intellectual potential, material and financial costs. The structure of the use of energy resources that has developed in some countries is unjustifiably wasteful, and the rate of growth in the consumption of coal, other cheap raw materials and the energy excellence of resources is insufficient. Meanwhile, energy shortages are observed in most countries of the world, in particular in the countries of the EU and Ukraine.

An example of resource-saving trends in the consumption model can be [5] Japan and France (see Fig. 6 [5]). However, in view of the Fukushima nuclear plant accident, Japan is radically revising its plans for nuclear energy.

Canada can be named among energy-consuming countries. At the same time, more than 60 % of global energy consumption falls on countries with a high level of expenditure (only 15.8 % of the world's population lives in them) [5, 39].

The structure of energy consumption by type of fuel in the period from 1998 to 2008 is shown in Table 1 [5]. It follows that global energy consumption is steadily growing, although oil consumption has slightly decreased against the background of a slight increase in the consumption of coal and natural gas and against the background of a drop in demand for nuclear energy.

Contrary to forecasts, according to various data, non-traditional, renewable energy sources are still not very present on the energy market. According to the International Energy Agency (IEA), in 2004, renewable energy sources (without hydroelectric PP) accounted for 13.5 % of total energy consumption, and biomass, according to World Bank estimates, accounted for 10 % [5, 37].

The structure of consumption looks different for different countries as well (see Table 2 [5]).

For the past decade, oil has remained the main source of energy in the energy balance remains oil, but the average annual growth of its consumption was 2 times lower than natural gas and 2.5 times lower than coal. Thus, the share of oil in total consumption fell from 38.8 % to 34.8 % [37].

Global energy security in any country is determined primarily by the provision of necessary reserves of hydrocarbon raw materials and other energy sources (hydroelectric PP, nuclear PP), but also depends on the problems of extraction, distribution, transportation and efficiency of raw material use.

The time of cheap energy is over for Europe, and not only for Europe. Dependence on imports (according to forecasts) will only grow – from 50 % of total energy consumption today to 65 % in 2030, in particular for gas imports from 57 % to 84 %, oil from 82 % to 93 % [37].

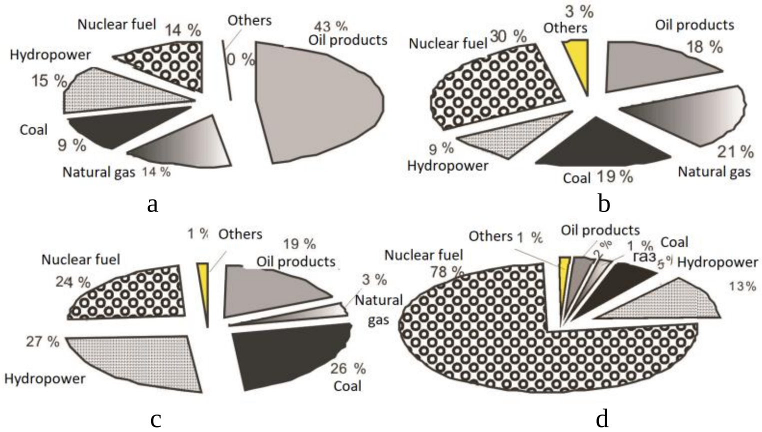

Figure 5 – The structure of the use of energy resources in Japan and France [5]:
a, b – Japan; c, d – France; a, c – 1980; b, d – 2000

Table 1 – The structure of world energy consumption by types of fuel [5]

Type of fuel	1998	2003	2007	2018	Average annual growth rates	
					2007	2018
Global energy consumption, million tons (in oil equivalent)	8889	9811	11104	11295	2.5	1.7
Oil, %	38.7	37.4	35.5	34.8	1.5	0.3
Natural gas, %	23.1	23.9	23.9	24.1	2.9	2.8
Coal, %	25.4	26.5	28.8	29.2	3.9	3.4
Nuclear energy, %	6.2	6.1	5.6	5.5	1.4	0.5
Hydroenergy, %	6.6	6.1	6.2	6.4	1.9	3.1

Table 2 – The structure of energy consumption of the largest countries
by types of primary fuel in 2018 [5]

Country	Consumption, million tons (in oil equivalent)	Distribution, %				
		Oil	NG	Coal	Nuclear	Hydro
USA	2299	39	26	25	8	2
PRC	2003	19	4	70	1	6
RF	685	19	55	15	5	6
Japan	508	44	17	25	11	3
Canada	330	31	27	10	7	6
Germany	311	38	24	26	11	1
France	258	36	15	4	39	6
Brasil	228	46	10	7	1	36
GB	212	37	40	17	6	0
Italy	177	46	40	9	0	5
Spain	144	54	24	10	9	3
Ukraine	132	12	41	30	15	2

Against the background of the above, in order to ensure the energy security of the state and the standard of living of the population, Ukrainian state policy should be aimed at protecting the country from energy risks. Taking into account the geopolitical, macroeconomic, social and scientific development of Ukraine, in March 2006, the Cabinet of Ministers of Ukraine developed and adopted the «Energy Strategy of Energy Conservation of Ukraine for the period until 2030», which was updated in 2008 [5]. The energy strategy is primarily aimed at reducing the energy intensity of domestic production, developing the export potential of energy at the expense of electricity, optimizing the production of one's own energy resources, diversifying external sources of energy products, and attracting non-traditional energy sources. In addition, the Cabinet of Ministers of Ukraine approved the «Concept of the targeted scientific and technical program for the development of the production and use of biological fuels» and other by-laws [5].

Organic fuel supplies to Ukraine in 2005 accounted for 60.7 % of total consumption. In the structure of primary energy consumption, the largest volume is occupied by natural gas – 41 %, oil – 19 %, coal – 19 %, uranium – 17 %, hydro resources and other renewable sources – 4 % [5].

The high energy intensity of the Ukrainian gross domestic product (GDP) is a consequence of the low manufacturability of most branches of the national economy (see Fig. 7 [5]). In this regard, the projected development of Ukraine's economy plans three stages of development and the first stage of development until 2010, which was the stage of structural restructuring. Unfortunately, it was revised in connection with the global economic and financial crisis.

Three scenarios for the development of GDP production volumes (optimistic, pessimistic, and basic) (see Fig. 8 [5]) suggest an almost three-fold growth with a two-fold reduction in the energy intensity of GDP. According to the Energy Strategy [5], the consumption of energy resources by 2030 will amount to 302.7 million tons, the planned level of consumption of coal, oil and gas is shown in Fig. 9.

Similarly, in global practice, countries strive to increase the production and use of coal, natural gas, and alternative energy sources.

Therefore, in the near future, Ukraine, like the rest of the world, will consume a large part of organic fuel. As elsewhere, natural gas consumption will increase in Ukraine, although the Energy Strategy [5] plans to reduce the rate of its consumption. But it can be assumed that this will happen at the expense of energy saving, and the use of natural gas as a motor fuel will grow. Special attention is paid to the gradual replacement of liquid motor fuel with compressed gas. Fig. 10 shows the dynamics of replacement of traditional fuel.

Today, Ukraine has more than 55000 vehicles that use compressed gas as motor fuel, and 161 special auto gas filling stations. If in the EU by 2020 it is expected to convert 10 % of vehicles to gas, then in Ukraine it is also foreseen (see Fig. 11 [5]) to increase the use of compressed natural and liquefied gases to replace liquid motor fuel [5]. According to the estimates of the Gas Institute of the NAS of Ukraine, in 2020, 75000 units of tractor agricultural machinery with diesel RICE were expected to be converted to gas.

In addition, the use of liquefied propane-butane mixture as a motor fuel is expanding. In the balance of light oil products, this type makes up only 0.5 % so far. The dynamics of production of propane-butane mixture is expected from 294 thousand tons in 2000 to 1075 thousand tons in 2030.

An important factor in increasing the level of energy security of Ukraine and reducing the level of anthropogenic impact on the environment is the development of alternative and renewable energy sources. The annual energy potential of non-traditional and renewable energy sources that is technically achievable in Ukraine in terms of conventional fuel is 79 million tons, the potential that is economically achievable under the base scenario reaches 57.7 million tons. Today, non-traditional and renewable energy sources make up about 7.2 %, in particular bioenergy about 0.8 % of the total consumption.

Promising directions for the development of alternative energy sources include bioenergy, extraction and utilization of mine methane, and the use of secondary energy resources. It is assumed that bioenergy is capable of developing at the fastest pace, and it is expected that the energy use of all types of biomass can provide an annual replacement of 9.2 million tons of conditional fuel of natural gas until 2030 [5].

It is expected to increase the volume of use of biogas from waste to 130 million m^3, reduce the volume of CO_2 emissions by 9 million tons per year. Due to the use of biodiesel as motor fuel, reduce the emissions of hydrocarbones and particulate matters by 50 %, carbon oxides by 40…45 %, nitrogen oxides by 5…10 %, soot by 60 %, the volumes of CO emissions as a result of using of ethanol should be halved.

An analysis of the use of unconventional fuels in the world shows that large-scale use of these fuels is impossible without state support. This is discussed in the «Green Book» of the EU, the legislation of the USA and the countries of Western Europe, where the advantages provided for the production and use of biofuel are unprecedented.

Taking into account the described above indicators, it is worth noting that the Energy Strategy of Ukraine [5] has far-reaching plans: the projected share of non-traditional and renewable energy sources in the balance of demand for energy resources by 2030 should increase to 19 %, in particular for renewables – up to 11.74 %. For comparison, in the EU countries, the growth of the latter is planned to 12.2 % (see Table 3).

According to [41], in the coming decades, oil will remain the leading source of energy, providing about 40 % of energy consumption. The share of natural gas in the total volume will be 28…28.4 %, coal – 20 %, renewable sources – 7 %, nuclear energy – 4.5–5 %. There is an increase in the share of oil – 40 % against 33 % and gas – 28 % against 18 % [5]. The share of nuclear energy is decreasing, but perhaps with the advent of new nuclear technologies, the level of its consumption will stabilize.

Therefore, analyzing different points of view, we can conclude that the role of traditional energy carriers in the global fuel and energy balance will not fundamentally change until 2025: oil is an energy carrier of global importance, gas is a regional energy carrier, and coal is a local one, and against this background, the interest of industrial advanced consumers to the problems of alternative energy development.

In the distant future (the second half of the 21st century), the transformation of the structure of the world energy balance is expected according to two scenarios:

– the first scenario envisages a gradual transition from oil to gas (as at one time oil replaced coal) with the preservation of the importance of the position of oil as an energy source, in any case, until the middle of the 21st century. Then a shift to renewable sources and, obviously, to nuclear energy with the creation of a new generation of reactors is expected;

– according to another scenario, the reduction of oil consumption will begin earlier (by 2025), if in the next decade progress is made in the field of hydrogen technologies, which contribute to the displacement of gasoline and diesel diesel engines by hydrogen ones.

The above analysis allows us to conclude that the global energy crisis will grow and deepen, and this will undoubtedly expand the limits of the use of alternative energy sources, in particular, alternative fuels, but the basic trends will not be affected, at least during the next 15…25 years.

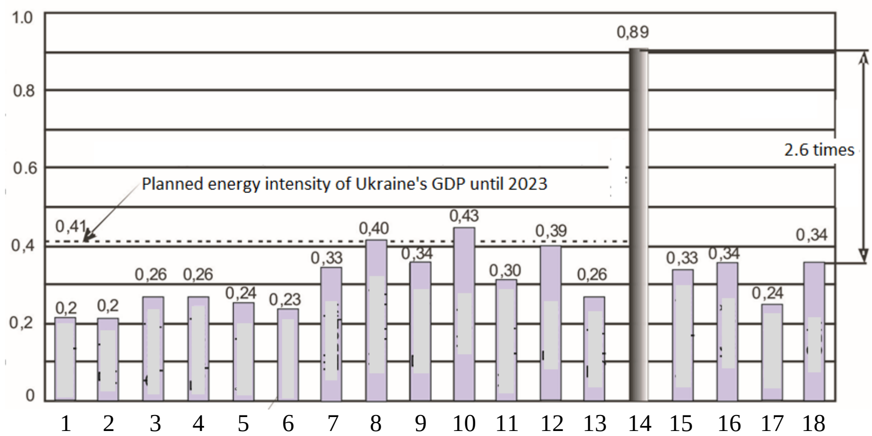

Figure 6 – Energy intensity of GDP in some countries [5]: horizontal axis – energy intensity of the country's GDP; vertical axis – production of fuel in billion kg of conditional fuel per $1;
1 – Austria, 2 – Danmark, 3 – France, 4 – Germany, 5 – Spain, 6 – Great Britain, 7 – Sweden, 8 – Finland, 9 – Poland, 10 – Czech Republic, 11 – Hungary, 12 – Lithuania, 13 – Turkey, 14 – Ukraine, 15 – Australia, 16 – China, 17 – Japan, 18 – World

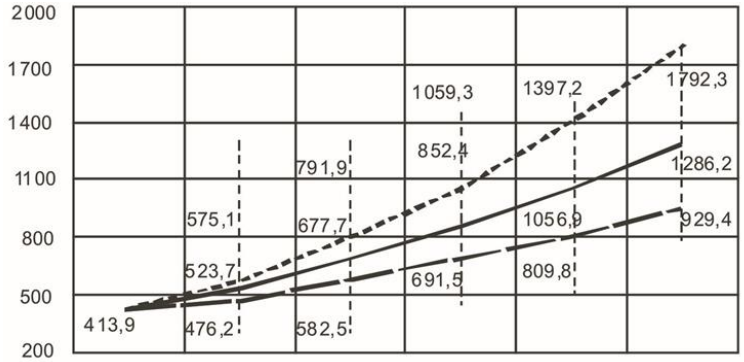

Figure 7 – Forecast of GDP production volumes (prices of 2005) [5]: horizontal axis – date in years; vertical axis – production volume of the country's GDP in billions of hryvnias (in 2005 prices); development variants: small dotted line – optimistic; solid line – basic; large dotted line – pessimistic

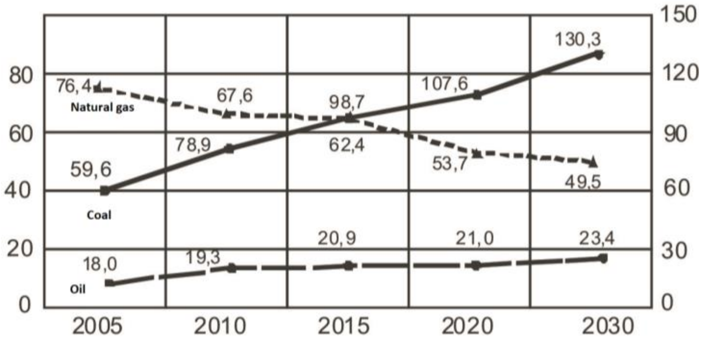

Figure 8 – Forecast of consumption of coal, oil and natural gas in Ukraine [5]: horizontal axis – date in years; vertical left axis – NG consumption in billion m^3, vertical right axis – consumption of oil and coal in million tons

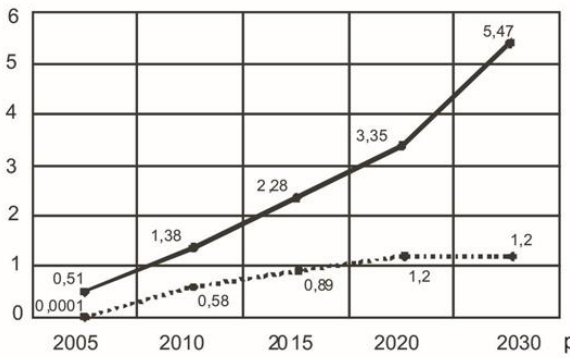

Figure 9 – Dynamics of replacing liquid fuel with natural gas [5]:
horizontal axis – date in years; vertical axis – NG consumption in billion m^3
dotted line – in transport; solid line – in agriculture

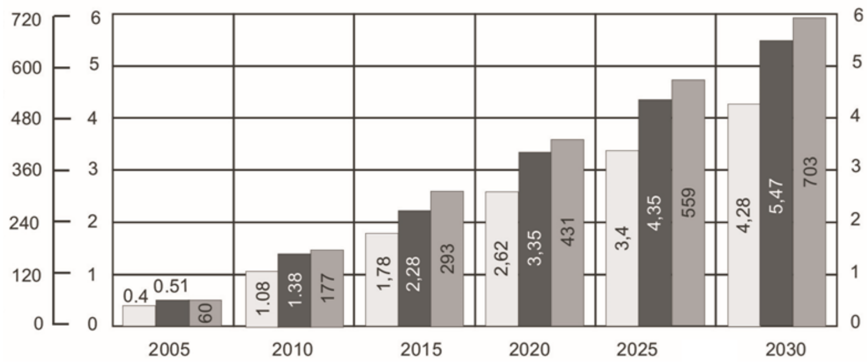

Figure 10 – Forecast of the use of compressed gas as motor fuel [5]:
horizontal axis – date in years; vertical left axis – amount of vehicles in thousands units and amount of motor fuel that is replaced in million tons in ratio 120 : 1; vertical right axis – amount of compressed NG for replacing of liquid motor fuel in billion m^3; light – volume of replaced motor fuel; medium – number of vehicles; dark – volume of replacing NG

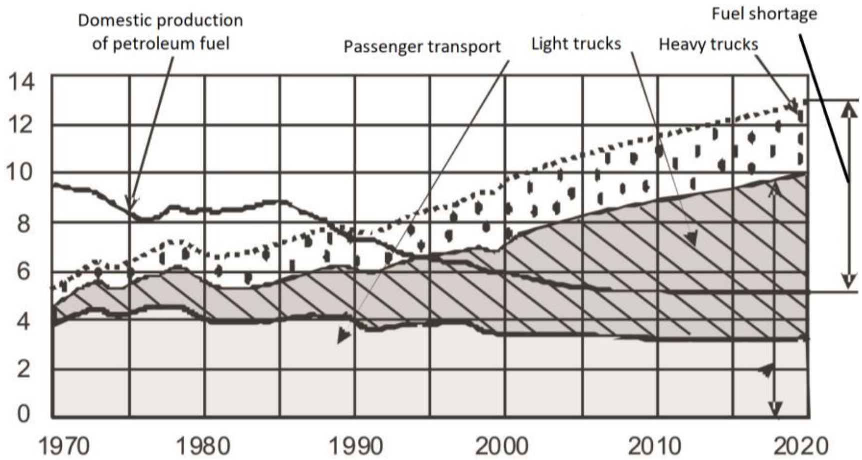

Figure 11 – Domestic production of petroleum fuel and its needs for transportation in the USA [5]:
horizontal axis – date in years; vertical left axis – consumption in million barrels per day;
emission of CO_2 in tons per km: 325 in 1990, 384 in 2000, 455 in 2010, 507 in 2020

Table 3 – The balance of demand for primary energy resources in the EU [5]

Energy source	Demand for primary energy resources in the EU, %				
	1990	2000	2010	2020	2030
Solid fuel	27.8	18.5	15.8	13.8	15.5
Oli	38.3	38.3	36.9	35.5	33.8
NG	16.7	22.8	25.5	28.1	27.3
Nuclear energy	12.7	14.4	13.7	12.1	11.1
Renewable sources	4.4	5.8	7.9	10.4	12.2

We will turn to the main consumer of energy resources – transport: automobile, railway, sea and air. Today, 80 % of all oil derivatives are spent precisely on its needs [5]. As a result, in countries with high traffic saturation (regardless of the existence of their own oil resources), petroleum products account for 36…46 % of total energy consumption (Japan, Italy, USA, Great Britain, France, Ukraine). In addition, transport is a key component of the European economy, the economies of the CIS, China and other countries [5].

Today, the world's automobile fleet is estimated at about 900 million units, of which about 30 % are freight vehicles, 70 % are passenger cars and public transport. By 2020, the world car fleet will exceed 1 billion units [42]. And all this multitude of cars require gasoline, diesel fuel, masute – the main derivatives of oil. The transport sector of the countries of the post-Soviet space is also increasing, and according to the US Department of Energy, the average increase in oil consumption in the transport sector of these countries for the period until 2020 is 2.9 % per year. Using the example of the USA itself, one can notice the growth of oil consumption by various types of motor vehicles [43] (see Fig. 12 [5]) and see how the surplus of consumption over the production of oil fuel in this country is growing. Obviously, the situation will be slightly different in other countries.

In addition, it is rational to takes into account the increase in the level of motorization of the population, which also leads to an increase in the demand for oil and to significant changes in the structure of transportation.

In countries that independently extract crude oil and other fuel hydrocarbons, as well as produce various types of motor fuel from raw materials of their own production in quantities that allow not only to cover their own needs, but also to export such raw materials and products of their deep processing, the following trends are present: passenger transportation by rail was reduced from 30 % to 20 %, and road transportation increased from 40 % to 55 %. Freight transportation by rail was reduced from 65 % to 5 0%, by road – increased from 8 to 16 % [5].

It can be argued that with a small error in one direction or another, there is the situation which is typical for any industrial country – all these trends change the fuel and energy balance of any country, increasing the consumption of motor fuels and requiring special attention to the state of the environment, especially cities, since 40 % of total industrial emissions into the atmosphere are caused by transport. In large cities, this figure reaches 90 %, and the amount of environmental damage caused by industrial emissions reaches 2 % of the GNP, in particular, 60 % of the damage is caused by road transport [5].

Transport RICE are the main type of energy converters and the main consumer of motor fuels. In the nearest future, diesel engines are unlikely to be replaced. Therefore, the problem of saving traditional motor fuel and reducing the toxicity of RICE must be solved based on this situation. As a result of such a conclusion, several directions for solving the given problems can be outlined:

a) further improvement of the design and working processes of modern RICE, both diesel and spark-ignition engines:

1) designing the engines with combined cycles, combined fuel-air mixtures, which can operate on super-depleted working fuel-air mixtures;

2) designing and wide application of modern systems of automatic management of work processes of RICE;

b) using of alternative fuels of all types, from natural gas to fuel from biomass and waste;

c) designing the combined PP, when an RICE is used as the main source of energy, and an electrochemical battery or energy storage is used as its peak source (flywheel, battery of electric capacitors, etc.);

d) transition to electric cars and cars with fuel cells. A number of disadvantages of electric cars – high cost of non-ferrous and rare metals, lack of established production of powerful traction batteries and networks of charging stations, problems of battery disposal, small range, do not allow them to become mass transport, and cars with fuel cells remain too expensive. Obviously, viable are symbiotic combined PP – RICE–electric motor are viable.

Permanent painstaking work is carried out in each of these areas.

It might seem that modern engines of the world's leading engine manufacturers have reached the limit of their improvement. But legislative and financial stimulation by the state and commercial structures helps to create a new generation of cars and engines of a new generation, competitive both in terms of fuel consumption and toxicity.

Of course, life always makes adjustments, but it's clear that diesel engines, despite all their shortcomings, will remain the main energy converter for vehicles for the foreseeable future. First of all, it is obvious that the gradual and very slow replacement of petroleum fuels does not involve the development of special engine designs, but only their possible adaptation to new alternative types of fuel, without diminishing the task of improving diesel engines on traditional fuels. The above analysis makes it possible to determine the range of tasks that require an urgent solution.

Currently, the majority of transport PP operate on liquid motor fuels of petroleum origin. In the overall global balance of motor fuel consumption, the percentage of these types of fuel is 95 %, and cars and heavy trucks account for almost 80 % of this value. The role of oil in the transport sector will decrease slightly in the future, but even by 2030 its consumption will not be less than 90 %. The share of biofuel and natural gas will account for 5 % of the fuel consumed by transport [5].

In connection with the forecast growth in the number of transport and, accordingly, the volumes of oil consumption, there is a tendency to increase the production and use of liquid motor fuels of non-petroleum (mainly biological) origin or mixtures based on petroleum, biological, and gas fuels.

In this case, at least two problems are solved on a global scale:

– partial replacement of petroleum fuel with alternative (biological) fuel;

– reduction of the level of environmental pollution by harmful components of exhaust gases.

The transfer of transport RICE to consumption of alternative types of fuel, which are new types of fuel compared to conventional oil, raises a number of questions of a scientific and technical nature. The problems are caused to the fact that the bulk of the engines of the modern transport fleet were designed and created for petroleum fuel (gasoline, diesel fuel), and when using alternative types of fuel, the processes inside the engine differ from processes using petroleum fuel. This makes it necessary to solve a number of problems of effective use of alternative fuels in traditional RICE – their adaptation to new types of fuel is necessary. Adaptation involves solving a number of tasks of a scientific, technical and economic nature.

The task of scientific research is to study the processes of fuel mixing, combustion processes and the formation of harmful substances in the combustion chamber of the engine. In addition, these tasks are very different for diesel engines and engines with forced ignition of the mixture.

Tasks of a technical nature – studying the influence of alternative fuels on the functional characteristics of motor oils, and therefore on the life of engines, determining the optimal control characteristics of the engine for each new type of fuel (and there can be many types of mixed fuels), ensuring the compatibility of fuel communication materials and new types of fuel, provision of the necessary resource of fuel filters, adaptation of engines to work on different types of fuel with the help of adaptive control systems.

The task of an economic nature is the provision of the necessary raw material base for the production of alternative (biological origin) fuels, the formation of the appropriate infrastructure, i.e. the network of appropriate gas stations, service, training of appropriate specialists, etc.

Another solution to some of these problems is the development and production of engines designed to use new types of fuel, but given the number of transport and other types of diesel engines currently in exploitation, this path can only be realized for a long time.

Common types of fuel for alternative liquid motor transport are combustible gases – methane, propane-butane mixtures, shale gas, blast furnace gas, mine gas, generator gas, biogas (similar in composition to methane), hydrogen. The most compelling alternative now is natural gas in a compressed (CNG) and liquefied (LNG) state, which successfully competes with the propane-butane mixture, the prices of which are linked to the increase in the prices of petroleum products.

At the beginning of the 21^{th} century, due to its low cost and well-established production, natural gas occupies one of the first places among alternative fuels. It should be noted that this fuel was used in engines more than 100 years ago, and the first engines were gas-powered, and only the development of the oil industry, the appearance of gasoline and diesel fuel pushed back its new demand for many years. The advantages of using natural gas are manifested not only in its considerable cheapness, but also in reducing the negative impact on the environment.

Statistics from different sources may differ slightly, but the general trend is that the world fleet of gas-powered cars is increasing. In general, gas is used for about 1.5 % of the world's car fleet, which is less than 1 % of the total gas consumption. The majority of gas cars are operated in Pakistan (2.5 million), Iran (2.07 million), Argentina (1.9 million). 200000 such vehicles are operated in Ukraine [5].

Leading car companies Mercedes, BMW, Volkswagen, Volvo, Opel and others began to mass-produce more than 80 models of cars running on natural gas. However, the main source of growth in the number of gas cars in the world remains the conversion of vehicles during exploitation. The forgotten gas diesel for heavy equipment is also returning to the market.

In addition, in the global balance of gas alternative types of motor fuel, there is biomethane of the second generation, obtained during the processing of organic waste, which is the best motor fuel in the moral sense. Methane-hydrogen mixtures have also confirmed their economic and ecological efficiency.

The share of each type of gas fuel gas is constantly changing. The share of LNG in comparison with propane-butane mixtures is gaining a characteristic trend of growth. In particular, in 2007, the world fleet of cars running on propane-butane mixtures numbered 13.7 million units, and almost twice as many – 7.1 million units, mainly passenger cars, operated on LNG. By the end of 2018, the global fleet of cars running on LNG, liquefied natural gas and biomethane grew to 14 million, and 17 million units ran on propane-butane mixtures. Propane continues to be a popular fuel, but the rate of growth of the fleet of such vehicles is decreasing [5]. In the same work, with reference to the IEA (International Energy Agency), it is noted that the demand for methane fuels already exceeded the demand for propane-butane mixtures in 2020.

The promotion of alternative types of gaseous fuel on the world market, the extensive accumulated experience of using gaseous fuel for RICE, testify to the relative simplicity of adapting traditional engines to gaseous fuel, improving their operational characteristics and toxicity indicators.

Gaseous fuel is especially convenient and effective for stationary high-power PP, both with diesel engines and with spark ignition engines. In such installations, the amount of lost thermal energy of the fuel has a great absolute value and its disposal makes sense with a simultaneous significant increase in the efficiency of the installation as a whole (the heat of exhaust gases, cooling liquid, engine oil, compressed air is utilized).

2 Analysis of the nomenclature and properties of fuels of non-petroleum origin

2.1 Natural gas

Combustible gases, which accumulate in the people's rule in the ashtray of burning or chemical syrup, are divided into natural and artificial ones. Natural gas (NG) itself and associated gas that accompanies naphtha are produced above the ground. Piece gases are obtained in the process of processing solid or rare fuel or by-products of various production processes.

NG is a mixture of various hydrocarbons.

The main hydrocarbon component of NG is methane (CH_4), which in the gas source changes from 60 % to 98 %, in addition, NG contains ethane (C_2H_6), propane (C_3H_8), butane (C_5H_{12}) in small quantities, nitrogen, sour gas, carbonaceous gas, sawdust and water vapor. In some natural gases there is hydrogen sulfide (H_2S), instead of which it does not exceed 3–4 %.

The NG warehouse includes flammable (water, methane, carbon oxide) and non-flammable (nitrogen, carbon dioxide, tar, carbon dioxide) parts. The skin from these warehouses pours into the aroma of NG as a burning sensation, immersed in the reduced heat of combustion. The increase in carbon oxide (CO) increases the combustion heat of 13.250 MJ/m^3, while reducing the CO_2 and N_2 ballast increases the combustion heat and combustion temperature of low-calorie gases. An increase in CO in the storage of high-calorie gases reduces the heat of combustion. Reduces the heat of combustion and removes gas from the unsafe presence of O_2, which should not be more than 1 % of the volume. The presence of N_2, which consumes 713.140 MJ/mol to break the bonds of atoms, is also reflected in the energy value of combustible gases.

The typical composition of NG in volume fractions is given below: CH_4 goes from 60 % to 100 %, ethane – from 0 % to 12 %, propane – from 0 % to 6 %, butane – from 0 % to 4 %, pentane – from 0 % to 4 %, N_2 – 0.16 %, CO_2 – 0.16 %, H_2S – 0.1 %.

Before supply to consumers, NG is dried, cleaned of dust, and hydrogen sulfide is removed from it. All NG from gas fields are lighter than air.

Oil industry gas is contained (so-called associated gas) in a dissolved form in oil (in 1 ton of oil at a pressure of tens of megapascals dissolved from 50 to 600 m^3 of gas depending on the deposit). When extracting oil to the surface and reducing the pressure, the gas contained in it is released. Accompanying gas is separated from oil in separators, and then valuable chemical products and carbohydrates, which are easily liquefied, are extracted from it.

Unlike NG, petroleum gas contains less methane and more heavy hydrocarbons. Therefore, the heat of combustion and its density are higher than NG.

Associated petroleum gas, which can be stored in a liquefied state at a pressure of 1.6 MPa, is also used as an alternative fuel. The composition of petroleum gas is according to the season: in summer – 75 % butane, the evaporation temperature of which is 0.5ºC, in winter – 75 % propane, the evaporation temperature of which is 45ºC. This cheap fuel (its cost is lower than gasoline) will disappear as oil reserves are depleted. It should be noted that often this raw material simply flies into the «pipe» and causes additional damage to the environment.

Liquefied gases are a mixture of hydrocarbons, mainly propane and butane, with small impurities of heavier ones. The sources of their production are associated gases of oil and gas condensate fields and gases produced during oil processing.

Under atmospheric conditions, liquefied gases change to a gaseous state, and when the pressure increases or the temperature decreases, they turn into a liquid. For transportation and storage, these gases are usually liquefied, and consumers use them in the gas phase.

In perspective, it should be noted that a huge amount of methane (at least 104 quadrillion m^3) is stored in methane hydrates lying in the sediments of the World Ocean. Melting 1 m^3 of methane hydrate granules yields up to 200 m^3 of methane and 0.87 m^3 of fresh water. In the Black Sea, methane hydrates lie at a depth of 200…400 m.

Wide use of NG in the national economy as a raw material, technological and energy fuel is due to a number of technical and economic factors. The main ones are the universality of gas fuel and its thermal and operational properties. A relatively small amount of gas fuel is used in transport, about 52.1 billion m^3 (Ukraine, BP StatisticalofWorld, 2011). However, it will grow in the future. This is related to the problem of creating alternative fuels instead of gasoline. The use of gaseous fuels, in particular liquefied gases, NG and, in the longer term, hydrogen and synthetic fuels, is considered the most realistic.

Ukraine is a fairly advanced user of alternative motor fuels: 4.6 % of cars in the country use methane (NG) and 11.8 % – liquefied hydrocarbon gas.

The total demand for methane in the automotive segment of the gas market amounted to almost 1 billion m^3 (2017). Liquefied hydrocarbon gas (LPG) is a mixture of hydrocarbons (propane, butane, propylene, butylene) with an excess pressure of saturated vapors of not more than 1.6 MPa at a temperature of 45°C and not less than 0.07 MPa at a temperature of 30°C. LPG is used as a motor fuel for refueling motor vehicles because of its ecological and heat-technical characteristics, which are better compared to diesel fuel and significantly better compared to gasoline.

NG can be successfully used as motor fuel in RICE. In addition, gas has a number of advantages compared to gasoline. So, for example, the efficiency of gas engines is 40 % in a wide range of regimes, while the efficiency of gasoline engines is only 35 % at optimal loads. When replacing gasoline with gas, according to the data, emissions of toxic components into the environment are reduced, on average, by carbon monoxide by 5…8 times, hydrocarbons – by 3 times, nitrogen oxides – by 1.2…1.5 times, polyaromatic hydrocarbons – by 10 times, opacity – 8…10 times, carbon dioxide emissions by 20…25 % [5]. In addition, when converting engines to gas, oil consumption is reduced by 1.5…2 times, and there is also a decrease in engine wear. It is also 30…60 % cheaper compared to gasoline and diesel fuel. All these advantages make the use of NG in engines very promising.

However, problems arise in the storage and distribution of gas for transport engines, since gas can only be used either in a compressed (up to 20…25 MPa) or in a liquefied (–162°C) form. This requires additional costs both in the equipment of gas distribution stations and in the device of the vehicle (car). Compressed NG can be successfully used in both spark-ignition engines and diesel engines

NG, which has the highest hydrogen and anti-knock index (among hydrocarbon motor fuels), is the most effective substitute for petroleum fuels for urban vehicles with RICE. High heat-technical and anti-detonation indicators of NG (methane), a wide range of changes in concentration limits of ignition of gas-air combustible mixtures allow to significantly increase the degree of compression in RICE with forced ignition, to realize energetically and ecologicaly highly efficient combustion of depleted gas-air mixtures. When it is used in the RICE, emissions of super-oxidants with exhaust gases (C_nH_m – carcinogenic hydrocarbons, NO_x, PM – particulate matters) are significantly reduced, and carbon dioxide (CO_2) emissions are also reduced (~ by 20 %). Therefore, the use of NG in city vehicles allows to ensure a significant economic effect as a result of reducing fuel costs and compensation for environmental damage, as well as reducing urban pollution [5].

In 60 countries of the world, more than 11 million cars run on NG, the mileage at one gas filling reaches 400 km. Argentina is the world leader (more than 1 million cars running on NG). According to the plans of the UN European Economic Commission until 2020 ~ 30 million cars or about a tenth of the European car fleet will run on NG, mainly city buses, minibuses, passenger cars, which are in individual use. The annual consumption of NG by such a number of vehicles is more than 50 billion m^3. In Germany, converting cars to use NG is one of the priority areas of energy development and ecological safety. In France, a ban has been introduced on the use of hydrocarbon fuels (except LPG) in municipal buses and garbage collection vehicles. Italy has introduced a ban on the construction of gas stations without a NG filling station.

Further improvement of the economic, ecological and dynamic characteristics of gas engines is achieved due to the additional use of synthesis gas (H_2 + CO), which is prepared by vapor-oxygen conversion of part of NG in a compact catalytic reactor of the mine type directly on board the car using a microprocessor control system. The most common method of obtaining hydrogen is the catalytic conversion of NG methane with water steam. The primary product of methane conversion is synthesis gas, which is then subjected to secondary conversion. Therefore, a sharp improvement in the quality of NG combustion due to the introduction of syngas initiator additives leads to the possibility of working on leaner fuel mixtures, fuel economy and a further significant reduction in the levels of superoxidant emissions.

In particular, according to the data of a number of motor transport enterprises in the city of Kharkiv, Ukraine, the minimum costs for fuel components are ensured when operating even traditional cars with the modernization of gasoline RICE to run on NG. A route minibus-taxi with a modern highly economical gas engine (with the same mileage in city conditions) will approximately consume no more than 17000 m^3 of NG. Annual savings on fuel alone will amount to at least 10 thousand dollars, taking into account the difference in the cost of cars (~ 4 thousand dollars) and without taking into account the significant reduction in ecological damage from the harmful effects of NG when exploitating cars with a gas engine. The results of research conducted on a car with a diesel engine also confirmed the high efficiency of using NG. Thus, the use of compressed NG in the gas-diesel process with an ignition dose of diesel fuel of ~ 15 % by mass made it possible to reduce fuel costs by ~ 20 %, and costs from ecological damage by ~ 24 %.

The program for the transfer of part of the urban road transport to NG must be economically justified for a specific region, carried out both at the state (which is very important) and regional (which is more realistic) levels, as well as on the basis of international cooperation.

2.2 Synthetic gases

Synthetic (also so-called artificial) gases are obtained during the processing of solid or liquid fuels or are by-products of some industries. Synthetic gases include coke, shale, generator and blast furnace gases.

Synthetic fuel gases are obtained from solid fuel either by the dry distillation method or by the residue-free gasification method.

Coke gas is produced at coking plants as a by-product in the production of metallurgical coke from coking coal. High-temperature coking of coal consists in dry distillation of crushed coal at a temperature of 1000…1150°C in special furnaces. As a result of this process, a solid residue (coke) and gaseous products are obtained. After removal of ammonia, aromatic carbo-hydrates and purification from impurities from the source gas, coke gas is used as fuel. The yield of coke gas (300…320 m^3 from 1 ton of coal) and its composition strongly depend on the temperature of the process and the grade of coal. Semi-coking gas is obtained as a result of dry distillation of coal (without air access) at a temperature of 500…600°C. Such low-temperature coking produces semi-coke, pitch, gas and water. From 1 ton of coal, ~ 120 m^3 of gas is obtained [5].

The gas of underground gasification of coal – mine methane is obtained as a result of igniting the formation and supplying air for combustion through special wells. World coalbed methane reserves exceed NG reserves and are estimated at 260 trillion m^3. The most significant resources are concentrated in PRC, RF, USA, Australia, South Africa, India, Poland, Germany, GB and Ukraine. The necessity, possibility and economic expediency of large-scale extraction of methane from coal seams is confirmed by the experience of a number of countries. According to American experts, this direction will develop steadily and by 2020, the global production of methane from coal seams will reach 100–150 billion m^3 per year, and in the future, the industrial production of mine methane in the world may reach 470–600 billion m^3 per year, which will amount from 15 % to 20 % of the world production of NG.

The practice of using mine methane as motor fuel has been known for a long time. Even before 1990, more than 90000 cars were running on mine methane in the USA, Italy, Germany and in GB it is widely used in the country's coal regions for regular buses [5].

Shale gas is produced by thermal processing of combustible shale in chamber furnaces. The process is similar to coking, but its main purpose is to obtain a number of chemical products and gas fuel. After cleaning, shale gas can be supplied to consumers in its pure form or mixed with NG. Shale gas is characterized by a high content of carbon dioxide (Table 4 [5]).

Generator gas is a product of thermal processing of solid fuel in the presence of an oxidizer, and the entire combustible mass of the fuel passes into the gas phase. The process is carried out in gas generators, and the oxidizer can be air, oxygen, water vapor or carbon dioxide. Depending on the composition of the blow, different generator gases can be obtained. If the process is carried out under atmospheric pressure, rather poor generator gases are obtained, called mixed, with a heat of combustion of 4.18…6.28 MJ/m^3. During gasification under pressure up to 1960 kPa and steam-oxygen blowing, generator gas with a heat of combustion of 14.65…16.75 MJ/m^3 can be obtained.

Blast furnace gas is a byproduct of iron smelting in blast furnaces. The process of formation of blast furnace gas is associated with the interaction of coke carbon with blasting and iron ore reduction reactions. The composition of blast furnace gas depends on the humidity and temperature of blast heating, its enrichment with oxygen, as well as additives to NG blasting. The amount of dry blast furnace gas produced per 1 ton of cast iron is 2200…3200 m^3.

2.3 Biogas

Biogas is an alternative fuel of biological origin.

As a result of the significant increase in the consumption of petroleum-based fuels in recent years, a shortage of traditional types of fuel, mainly such universal and convenient as oil, has begun to be felt in a number of countries. This fact has intensified the search for substitutes (full or partial) of petroleum-based fuels. The most effective way in this case is the use of renewable energy sources, FBO and their mixtures with traditional fuels.

Ukraine belongs to energy-dependent countries, therefore the use of FBO in the country is a promising direction that will allow not only to save oil fuels, but also to improve the environment due to the better environmental characteristics of RICE operating on FBO.

In Ukraine, there are real opportunities for the production of FBO. In particular, biogas, which is obtained from landfills of solid household waste, plant material and livestock waste, is a fairly effective fuel for RICE, but for its widespread use, the development of the appropriate infrastructure is required.

Table 4 – Calculation characteristics of artificial gases [5]

Gas	Gas composition , volume %							Density, kg/m^3	Heat of combustion, MJ/m^3
	H_2	CO	CH_4	C_mH_n	CO_2	N_2	O_2		
Coke	57.0	6.0	24.0	3.0	3.0	7.0	–	0.342	17.60
Slate	24.7	10.0	16.2	5.0	16.4	26.8	0.7	1.040	13.85
Generator (mixed)	13.0	27.6	0.6	–	6.0	53.2	0.2	1.141	5.15
Generator (steam-oxygen blowing)	53.4	23.1	15.3	2.7	2.9	2.3	0.3	0.576	15.70
Blast furnace	3.0	30.0	–	–	9.0	58.0	–	1.283	4.10
Underground gasification	16.0	11.0	2.0	0.2	19.4	51.0	0.4	1.195	3.90

In the 21st century, biogas can become one of the most important fuels that can replace traditional fuels. Biogas occupies one of the leading places among non-traditional renewable energy sources, both in terms of its potential distribution and relative ease of obtaining it (through anaerobic fermentation of any types of organic matter) and in terms of the possibilities of using existing equipment (with minor modifications) for its direct utilization. Anaerobic fermentation is the most profitable method of obtaining biogas from an economic point of view, in which, in addition to biogas, high-quality fertilizers are also obtained. All processes are carried out in special biogas generators – methane tanks.

Back in 1996, a pilot plant for the production of biogas was built at one of the sewage treatment plants in Stockholm. The installation made it possible to obtain 1000 m^3 of gas per day, which is equivalent to approximately 1000 liters of gasoline. Gas was mainly used in the boiler room, and 150 m^3 were used in factory gas cylinder machines. The municipality of Stockholm approved the program for the construction of two more plants (in the suburbs of Cholera and Hepriksdal) for processing waste and obtaining biogas for 1.5 and 3 million m^3 per year. At the same time, the city authorities solve the problem of reducing harmful emissions into the atmosphere from several sources at once: road transport, sewage collectors and landfills of organic waste.

At the same time, obtaining biogas in devices of various sizes is economically profitable and justified, if a constant flow of waste is processed [5]. «A.V. Enbom» company offers a reactor for the anaerobic treatment of agricultural waste with the production of heat and electricity. A farm for 1000 pigs can produce about 300 m^3 of biogas with a composition of: 70 % methane, 27 % carbon dioxide. The calorific value of biogas is 26.3 MJ/m^3, which is equivalent to 0.74 l of diesel fuel [5].

The use of different methods of energy utilization of biogas is mainly reduced to two alternative solutions that apply to any gaseous fuel – fossil or synthetic: burning the gas in furnaces of boilers or using it as fuel for engines. In the first case, the chemical energy of the gas will turn into thermal energy, in the second – into mechanical energy.

The advisability of using a particular technical solution is determined by considerations of simplicity and economy, the availability of other energy resources in each specific case. The choice of an alternative FBO for use in a specific area should be made by performing an appropriate analysis of the resource base, economic and ecological feasibility, the possibility of its production and use. In the countries where the experience of using FBO has already been accumulated, there are proven technologies for adapting RICE to a specific type of fuel, ensuring its effective and safe use. Many technical solutions are presented as «know-how». However, as shown by the results of tests of RICE on FBO in bench conditions and during the exploitation of vehiclesc have shown, the reserves for improving existing technologies are far from exhausted and give hope for obtaining higher economic and ecological indicators of RICE adapted to FBO. In Ukraine, there is currently no mass application of FBO on RICE installations, so the development of this direction is an urgent task.

Extensive experience in the utilization of biogas resources has been accumulated abroad, and a number of schemes have been developed that allow obtaining energy on its basis.

The use of technological schemes, which provide for the utilization of biogas to drive generator engines, turns the problem of gas engines into one of the main ones. In world practice, various designs of gas engines have been developed and produced. It should be noted that the use of engines for the utilization of biogas energy led to the emergence of problems related to the designs of these engines, their fuel supply, its composition and degree of purification. It is known that the use of designs of certain engines is determined by the specifics of biogas as a medium-calorie gaseous fuel. Therefore, for its disposal, it is advisable to use gas engines, the designs and features of which are well-known for their operation [5].

The production of gas engines abroad is quite well developed and a number of companies manufacture engines suitable for both traditional gas fuel (NG) and biogas. To increase their efficiency, many designs provide for the presence of a system of recovery of outgoing heat.

For example, the Austrian company Ienbacher Berke produces serial gas engines with an effective power of 30…2200 kW [45]. The biogas utilization scheme was also developed by the German company KXD Humbold, which is also successfully engaged in the design and production of gas engines operating on biogas [5]. The German company Mashinenwerke (Augsburg-Nuremberg) produces engines for NG, which are easily modified in the case of biogas. Engine power is 99…130 kW. The Daimler-Benz company (Stuttgart, Germany) produces a medium-power M407 engine that runs on NG with the possibility of its modification for biogas [5].

Diesel engines can easily be converted to run on gas fuel with minimal modification of the fuel supply system [5, 46]. In addition, the use of gas fuel in diesel engines is environmentally friendly. It can even be recommended even for closed rooms where there are high requirements for the cleanliness of the atmosphere.

2.4 Hydrogen

Hydrogen is an ecologically clean fuel.

Air pollution is currently a serious global problem. This leads to the need to use hydrogen as an alternative fuel. Hydrogen can be used as a fuel in transport (for RICE), in industry, and in everyday life. The interest in using hydrogen as a fuel is explained by its unique properties. First of all, it is high energy density (120 MJ/kg), huge reserves in nature of renewable raw materials for obtaining hydrogen (H_2O), non-toxicity of its combustion products. In the process of burning hydrogen, only vapors of distilled water and a small amount of nitrogen oxide (NO_x) are formed. At the same time, the burning of oil, NG, and coal is accompanied by emissions of combustion products into the atmosphere, dangerous for human health, which worsen the condition of the soil and surface water, destroy buildings, machines, and equipment.

At present, considerable experience has been accumulated in the organization of the working process of a RICE using hydrogen as a fuel, but the creation of the infrastructure for production, transportation, refueling of cars with such fuel, as well as the lack of on-board systems for storing a possible hydrogen reserve, which are acceptable for vehicles, remain problematic.

Accumulation of hydrogen on a car is possible in cryogenic vessels, in metal hydride installations or in high-pressure cylinders [48–50]. Recently, the possibility of using glass microspheres as hydrogen accumulators [5], as well as liquid organic carriers of hydrogen [51] has been expressed.

The cryogenic hydrogen storage system has a number of obstacles for mass application in vehicles. One liter of it only weighs 0.071 kg, that is, its density is 70.99 g/l at the temperature of 20 K. Therefore, liquid hydrogen requires cryogenic storage technology, such as special thermally insulated containers, and special handling typical of all cryogenic materials When working with liquid hydrogen, it is also necessary to observe fire safety measures. Even with thermally insulated containers, it is difficult to keep it at the low temperature required to keep it liquid.

One promising option is an on-board hydrogen storage system based on the use of metal hydride batteries. Metal hydride alloys are metal alloys that have a certain crystal lattice structure. Due to their small size, hydrogen molecules can fit inside the crystal lattice of the alloy, occupying the free space between the metal atoms. Additional studies of the behavior of metal-hydrogen systems in a wide range of temperatures and pressures are necessary to optimize the processes of filling such batteries with hydrogen and extracting it.

Welded vessels with double and multilayer walls are used to store gaseous hydrogen at pressures up to 100 MPa. The inner wall of such a vessel is made of austenitic stainless steel or other material compatible with hydrogen under high pressure conditions, the outer layers are made of high-strength steels. Seamless thick-walled vessels made of low-carbon steel designed for pressure up to 40…70 MPa are also used [52].

The use of hydrogen as an automotive fuel promises a significant improvement in the efficiency of spark ignition engines. In terms of mass energy capacity, hydrogen exceeds traditional hydrocarbon fuels by 2.5…3 times, alcohols by 5…6 times. Having a large diffusion capacity, a high combustion speed, wide ignition limits, with an ignition energy that is an order of magnitude lower than that of hydrocarbon fuels, hydrogen provides a unique opportunity to obtain a qualitatively new working process of RICE. Such a working process is distinguished by a high degree of perfection, better economic indicators, and the ability of the hydrogen-air mixture to work stably in a wide range of concentrations from $\alpha = 0.2$ to $\alpha = 10$ provides the possibility of engine operation in a wide range of speed regimes with qualitative and quantitative power regulation [53]. Therefore, hydrogen fuel can increase engine efficiency and reduce specific fuel consumption.

Today, conversion of RICE to gasoline-hydrogen composite fuel is also relevant. Mass additions of hydrogen during the combustion of depleted gasoline-hydrogen-air mixtures significantly increase the completeness of fuel combustion, reduce the levels of nitrogen oxides (NO_x) formation, inhibit the processes of formation of carcinogenic carbohydrates and PM. In the conditions of urban exploitation of passenger cars, when using depleted gasoline-hydrogen-air mixtures in RICE (the proportion of hydrogen is about 10 % of the mass), the following is ensured: a reduction in gasoline costs by up to 40 % (due to the replacement of gasoline with hydrogen and an increase in the operational efficiency of cars), a reduction in exhaust emissions gases (CO_2 – by approximately 40 %, NO_x – by five times, and carcinogenic carbohydrates – by an order of magnitude or more [54]).

A promising direction in hydrogen energy is the development of hydrogen fuel cells (FC). In FC, the chemical energy of the fuel and oxidizer, which is continuously supplied to the electrodes, is converted directly into electrical energy. The choice of fuel and oxidizer supplied in FC is determined, first of all, by their electrochemical activity – that is, the speed of reactions at the electrodes, the cost, the possibility of easy introduction of the reagent into the fuel cells and removal of the reaction products. Hydrogen is usually used as a fuel, air oxygen is the oxidizing agent. The price of hydrogen fuel cells is still quite high, but the reliability and ease of operation of such equipment compensate for this disadvantage.

Domestic sources of raw materials for the production of hydrogen are significant resources of stone and lignite, the reserves of which in Ukraine are of a regional nature [55]. During coal processing in mining areas, the resulting hydrogen can be transported to places of consumption by pipeline transport. Like any other gas fuel, it can be accumulated and stored for a long period of time both in conventional containers and in reservoirs of natural origin, for example, in produced gas fields.

The possibility of using hydrogen as a motor fuel was confirmed at the A.M. Pidgorny Institute of Mechanical Engineering Problems of NAS of Ukraine both by theoretical and experimental studies, up to tests on some types of vehicles. These developments were the first in the USSR and were not inferior to the world achievements of science and technology in this field at that time.

But hydrogen engines still have a distant perspective. And if in the 80s of the 20th century, assumptions were made about the mass use of hydrogen as a fuel for traditional engines in 30 years, then already in the 90s, its “expectation” no earlier than 2050 was substantiated. This is explained, first of all, by the cost of hydrogen fuel and the need for a radical reorganization of the entire infrastructure that serves road transport, and, in addition, by the fact that harmful emissions from factories that produce engines and hydrogen fuel for them can minimize all benefits.

In any case, it can be argued that the appearance of hydrogen as an alternative fuel on the fuel market will only become possible when fossil fuels are not consumed for their production, the cost of electricity will significantly decrease, which can happen, for example, in the case of industrial development of thermonuclear fusion. The use of hydrogen is a large-scale long-term strategy.

2.5 Nitrogen

Nitrogen is a fire-safe type of fuel.

Currently, special low-speed tractors with RICE are used for redeployment of aircraft within airports. For the movement of goods in the warehouses of the airport, special forklifts are also used, as a rule, with RICE. Vehicles with RICE, which are used at many enterprises or objects with increased fire danger (airports, docks, elevators, chemical plants, oil refineries), are sources of ignition due to the peculiarities of their technological (working) cycle. In particular, the operation of RICE can serve as a source of unacceptably high levels of the content of harmful substances emitted with exhaust gases. In addition, the vapors of petroleum motor fuels are also toxic. As an alternative to such vehicles, electric vehicles are often used, which, although they differ favorably, from the point of view of the ignition source, from vehicles with RICE, but can also be a source of fire (the operation of electric motors, contactors, relays, etc. can generate a spark discharge).

For the past few years, pneumatic and cryo-engines, which can be used as PP on special vehicles for the above-mentioned fire-hazardous objects, have become the object of intensive research by vehicle manufacturers [56, 57]. Pneumatic PP for cars that use high-pressure gas are considered as one of the promising options for cars of small and medium capacity.

The first experimental cars with cryo-engines used in the aviation industry have already been created in the USA [56] and, according to experts, they have a great future.

They are also interested in the development of small cars by the French company Motor Development International. In Ukraine, engineering and design works on the development of a highly efficient automotive pneumatic engine for a cryogenic PP is being conducted at the Kharkiv National Automobile and Highway University [5]. The coefficient of efficiency of such installations is still low, but the unique properties of the working fluid used support the high interest of researchers in them.

Nitrogen is an ecologically safe and chemically inert gas, which allows the use of cryogenic PP even in closed rooms, in particular those where flammable substances are stored or are a technological material.

Nitrogen is the most available non-flammable gas (~ 78 % in atmospheric air), which can be used as a working fluid for a piston cryoengine without disturbing the balance of its content in the atmosphere. Liquid nitrogen is obtained from atmospheric air at air separation plants, where its reserves are practically unlimited.

The advantages of using cryogenic PP in cars include: fire safety; environmental cleanliness; possibility of energy recovery; available production technology; availability and relatively low cost of the working medium (liquefied or compressed nitrogen, air); economic expediency (the cost of 1 km of mileage is less than for RICE) [5]; possibility of mass application in cities with a high population and motor vehicle density [58].

Conclusion

Thus, based on the results of the research, reflected in the sections of this work, the following general conclusions can be drawn.

The growth of industrial production in the world has led to a significant increase in the consumption of petroleum fuels. As a result, a number of countries have begun to experience the shortage of traditional types of fuel, mainly such universal and convenient as oil, which intensified the solution to the problem of finding substitutes (full or partial) for petroleum-based fuels.

The most effective ways in this case are the use of renewable energy sources, fuels of biological origin and their mixtures with traditional types of fuel.

Among the defining trends, which will be characteristic of global energy in the 21st century, there are:

– increasing the use of high-quality energy carriers of non-oil origin: NG and hydrogen-containing gases (coke, blast furnace, generator, biogas and other combustible gases);

– producing of synthetic fuels and, in the future, hydrogen from NG, coal, biomass and organic waste, development of hydrogen energy.

Based on international studies of the economic assessment of the consequences of atmospheric pollution, it has been determined that the largest share of the possible harm belongs to the ecological component associated with the impact of motor vehicle emissions in the urban environment on human health. As shown by the results of tests of RICE on FBO in bench conditions and during the operation of vehicles, the reserves of improvement of existing technologies are far from exhausted and give hope for obtaining higher economic and ecological indicators.

One of the important conditions for the successful use of alternative fuels as working bodies is creating modern engineering methods for calculating their paraliquid equilibrium and thermodynamic properties. These calculation methods must simultaneously meet such requirements as accuracy and the possibility of application in a wide range of pressures and temperatures while using a minimum of initial data.

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ДОСЛІДЖЕННЯ РОЛІ АЛЬТЕРНАТИВНИХ ПАЛИВ В ЕНЕРГЕТИЧНОМУ БАЛАНСІ УКРАЇНИ ТА КРАЇН ЄВРОПЕЙСЬКОГО СОЮЗУ ЗА ЧАСІВ ЗБРОЙНОЇ АГРЕСІЇ ТА У ПОВОЄННІЙ ВІДБУДОВІ ЕКОНОМІКИ ТА ІНФРАСТРУКТУРИ КРАЇНИ

У статті, яка відображає результати власного дослідження колективу авторів, метою якого було встановлення кількісних та якісних аспектів ролі альтернативних палив в енергетичному балансі України та країн Європейського Союзу за часів збройної агресії та у повоєнній відбудові економіки та інфраструктури країни, послідовно вирішено наступні задачі: аналіз споживання енергетичних ресурсів у світі й в Україні та використання альтернативних видів палива на транспорті; аналіз номенклатури та властивостей палив ненафтового походження. Об'єктом дослідження є роль альтернативних палив в енергетичному балансі України та країн Європейського Союзу. Предметом дослідження є кількісні та якісні аспекти об'єкту дослідження за часів збройної агресії та у повоєнній відбудові економіки та інфраструктури країни. Наукова новизна результатів дослідження полягає в тому, що набуло подальшого розвитку уявлення про застосовуваність різного виду альтернативних моторних палив для живлення енергоустановок з поршневим ДВЗ, зокрема одиниць пожежної техніки та аварійно-рятувальних транспортних засобів підрозділів ДСНС України, у частині вирішення ними задач як за часів збройної агресії, так і у період повоєнної відбудови економіки та інфраструктури країни. Практичне значення результатів дослідження, полягає у тому, що результати порівняльного аналізу номенклатури, властивостей та перспектив застосування різного виду альтернативних моторних палив для живлення енергоустановок з поршневим ДВЗ придатні для використання при побудові стратегічних засад функціонування одиниць пожежної техніки та аварійно-рятувальних транспортних засобів підрозділів ДСНС України за часів збройної агресії і у період повоєнної відбудови економіки та інфраструктури країни.

Ключові слова: традиційні моторні палива, альтернативні моторні палива, біодизель, бензоетанол, водень, технології захисту навколишнього середовища, екологічна безпека, енергоустановки, поршневі двигуни внутрішнього згоряння, пожежноа та аварійно-рятувальна техніка, збройна агресія, повоєнна відбудова.

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