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Ecological-and-economic Approach to the use of Recycled Biomaterials as an Energy Resource

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ABSTRACT

The problem of the traditional energy resources exhaustion which is also arising in the process of their exploitation as a factor of the environmental degradation is observed in the paper. The authors have analyzed the possibility of using alternative raw materials based on recycled plant biomaterials as renewable substitutes for energy sources. According to analytical data, it is shown that the biofuel demand as an alternative form of energy meets regulatory requirements that impose restrictions on the sulfur emission rate to the environment which are built up in the result of traditional combustible materials burning. The authors esteem the feasibility of all-around usage of various types of recycled biomaterials as a fuel. Within this framework, conducted study is a priority and promising direction for the world's economy and energy, and the analysis of the main technical and economic characteristics of various types of waste biomass.

Keywords: Environmental Safety, Renewable Energy Sources, Recycled Biomaterials
JEL Classifications: Q20, Q42, F52

1. INTRODUCTION

In current times, a common problem for many countries of the world is upcoming fuel crisis, increasing energy prices, environmental degradation. The exhaustion of natural energy resources (coal, oil, peat, natural gas), as well as environmental problems arising in the process of their use, necessitate searching and implementation of alternative renewable energy sources in practice (Nazarova et al., 2019). According to UN experts, the population may increase to 9.2 billion people by 2050. Maintaining of the current production rates of motor fuels and natural gas per head of population as well as the intensive use of combustible minerals will lead to a significant decrease in their reserves (18.3 billion tons of oil will have to be produced for the year – 16% of proven reserves and to 12 trillion m^3 of natural gas – 6.7% of proven reserves). In such a way, according to the forecasts, the oil reserves are enough for 6-10 years, and gas reserves are enough for 15-20 years.

The problem statement of plant waste using as an energy sources is compatible with the provisions of global cooperation documents connected with limitation and reduction of gaseous emissions which lead to the ozone layer the destruction on the planet (Kyoto Treaty, protocols of the United Nations Framework Convention and the IPCC – International Expert Group on Climate Change Assessment). It is estimated that the energy content of agricultural waste which is produced in the world is about $93 \cdot 10^{18}$ J/year. Assuming that the actual use of their potential to 25% can provide about 7% of world energy. The usage of recycled fuel biomaterials will make it possible to solve global environmental and economic problems, namely, reducing greenhouse gas emissions and the risk of acid rain by decreasing of emitted sulfur dioxide amount (forests preservation). And there are also local problems connected with the need to dispose large-scale industrial and agricultural waste annually generated by hundreds of thousands of tons, and at the same time to be able to receive additional economic benefits through waste biomass usage.

In this aspect, planning of integrated measures for the rational use of recycled bioresources is provided, and it is aimed at the negative impact reducing of accumulated biomass waste on the natural environment through its conversion utilization, as well as strategic course is developed to reduce the amount of industrial gaseous emissions (carbon dioxide, methane, sulfur compounds, etc.) that lead to the global warming on the planet.

2. LITERATURE REVIEW

It is known that sulfur and its compounds are presented in the composition of traditional raw materials: crude oil, gasoline, diesel fuel, coal (in the form of mercaptans R–SH, sulfides R–S–R, disulfides R–S–S–R, thiophenes, thiorphans and others; R – hydrocarbon radical). The combustion products of the above substances (SO_2 и SO_3) together with the exhaust gases, entering the atmosphere, have high toxicity and corrosive chemical aggressiveness (Myasnikova et al., 2019; Mazgarov and Kornetova, 2015). Therefore, the biofuel requirement as an alternative energy source is compatible with normative standards that limit the amount of sulfur emissions to the environment resulting from the traditional combustible materials burning. In addition, taking into account the rising prices for gasoline and diesel fuel in Europe, which have increased on average by 5.4% for AI-95 and by 2.5% for diesel fuel per three 1st months of 2019 (the price for a liter of gasoline has reached the average level of 1,3 € and 1,23 € for diesel fuel). So, a rational solution is considered to be an adoption of less expensive substitutions, containing predominantly combustible carbon and hydrogen elements, environmentally friendly energy producing materials. Such an approach will reduce the high prices of AI-95 gasoline in Netherlands, Norway and Iceland, which are by 25-30% higher than European average. (Flach et al., 2018).

In the context of the problem mentioned above, most EU countries, the USA, Canada, Brazil, Sweden, China and others are actively developing programs for the production and using of fuel based on various types of plant raw materials. Thus, according to the EU directive, it is planned to implement environmentally friendly and efficient types of biomaterials (renewable energy sources) into the fuel and energy sector (Myasnikova et al., 2019). One of the energy programs “Energy 21” was adopted in Denmark as early as in 1996. It suggests that renewable energy based on biomass should exceed 50% by 2030 in the general structure of fuels used in heat and electricity production. It is noted that the energy resource growth can achieve 2.4 times by increasing the usage of recycled perennial and annual plant raw materials (Gregg et al., 2014). Legislative support was introduced in this field by decision of the European Commission. Tax and customs department in Estonia has gained the right to excise tax exemption for liquid biofuels (no more than 5% of the total value of all fuel). According to the price monitoring data in Estonia, the cost of bioethanol based on biomass was at 10% lower than the cost of the most common AI-95 in Europe (Flach et al., 2018). Tax exemptions (so-called “green taxes” were established for biofuels, and the biofuels’ usage exempts consumers from energy taxes and environmental charges in Austria and Sweden. Effectively operating US federal laws with tax breaks are focused on bioethanol production, as well as on the support of waste vegetable and animal oils reutilization (Vasilov, 2007a).

According to geographic and climatic parameters, there is a large variety of vegetation types in many countries which are included in conversion production processes. It leads to the continuous formation of a large amount of organic waste (agricultural, chemical industries, wood processing, peat production, printing, food, textile and other industries).

Taking into account the fact that the energy resource costs based on waste biomaterials are practically minimum, and the fact that abovementioned cost volume is not limited, their economic feasibility is obvious.

Depending on the genesis, morphological, chemical and rheological properties of biological raw materials, various technologies of biomaterials’ energy usage are possible. Thus, technologists and ecologists note that along with thermochemical methods of the plant materials processing and their waste utilization (direct combustion, high-temperature gasification [Westinghouse Corporation], pyrolysis, etc.), the production of fuel briquettes, pellets, tablets and others forms is adopted as the most optimum alternative (Khoruzhenko and Dorogov, 2017; Sevastyanova, 2009).

However, mainly organic part of the plant biomass waste possesses energy capacity and chiefly consists of polysaccharide components, including cellulose, hemicellulose and lignin. It’s technically and economically effective that lignin acts as a gluing agent of the cellulose crystalline chains in the lignohydrocarbon complex, as well as it provides a mechanical function and is closely associated with hemicelluloses. It gives a possibility to do without additional agents. Total organic content in anhydrous plant biomass, including up to 12% of capillary moisture, is represented by carbon (45-50%) oxygen (40-45%), hydrogen (4.5-6.0%), nitrogen (0.3-3.5%) and a small amount of sulfur (up to 0.05%) (Sushkova and Vorobyov, 2008). The abovementioned components are converted into carbon dioxide (CO_2) and water vapor (H_2O) when it burns.

Biomass utilization rate for heat production reaches 15% in EU countries. At the same time, this indicator is significantly higher in many countries which predominantly use solid biomaterials. For example, 61% of heat is obtained from biomass in Sweden, 37% – in Austria, 35% – in Denmark, 32% – in Finland (Flach et al., 2018).

According to the International Energy Council, 1.9 billion m^3 of wood and about 300 million m^3 of wood biomass wastes were used at the beginning of the 21st century in the whole world. Considering that Russia possesses over 25% of the world's forest reserves, wood waste recycling is considered as a stable restoring energy source. (Pantshava, 2015).

According to wood prices' analysis of the Baltic countries, the average price of roundwood is € 63/1 m^3 in Estonia, just as it is € 41 in Sweden (Flach et al., 2018). The cost of fuel chips varies from 16 to 25 €/m^3 depending on humidity, fractional and qualitative composition (types of wood, lack of bark). Additionally, raw materials can be purchased in Russia. The maximum cost of 1 m^3 of coniferous wood at forest auctions has been reached 383 rubles in Kaliningrad region, 366 rubles in Penza, 252 rubles in Bryansk, 261 rubles in Vladimir, 218 rubles in Kaluga region. The cost of wood chips of fir-trees is 300-500 rubles/m^3 (8-20 mm fraction, humidity – 12%) in Russia, the price without bark amounts to 850 rubles/m^3, and the price of fuel wood briquettes made from waste chips (pellets) increases to 78-90 €/m^3 (National Biofuel Association, 2016).

These facts suggest that there is an economic feasibility of waste wood chips using for energy needs. Analysts at FOEX Indexes Ltd had calculated a price index for wood pellets in Central Europe and it reached € 202.76/ton. In the context of abovementioned facts, it should be noted that the energy concern DONG Energy, which is one of the largest consumers of pellets, has transferred the first block of a large thermal power plant in Avedore from coal to wood pellets. Now the capital of Denmark Copenhagen will be able to get more bioenergy (Flach et al., 2018).

It is estimated that burning wood (with 10% of moisture), which mainly consists of polysaccharides and lignin, provides for the thermal energy release in the amount of 14-15 MJ/kg (for comparison, low heating value of oil is 41-44, household gas is 32-33, and coal is about 27-29 MJ/kg) (Energy Strategy of Russia for the period up to 2030, 2010). The content of mineral part in the biomass is insignificant; therefore, after its combustion, there is almost no ash. In addition, using of alternative energy sources, which are more environmentally friendly and cost effective, eliminates the need to add additives to traditional fuel which neutralize the effect of sulfur fumes. Moreover, it also provides additional cost savings. Such approach emphasizes the feasibility of low-sulfur fuel biomaterials switching in energy industry and makes it possible to increase sustainability indicators for many energy-dependent countries.

3. METHODOLOGY OF THE RESEARCH

Technical analysis of air-dry wood samples pre-blended at special laboratory vibratory mills (laboratory vertical vibrating mill MVV-2) and annual plant waste (their individual parameters) was carried out in laboratory conditions according to standard techniques (Lamotkin and Bondarenko, 2005; Svietkina et al., 2017). The characteristics of target components of recycled plant materials is presented in Table 1.

The data in Table 1 indicates that the chemical composition of the plant biomass organic part with energy capacity is quite stable.

Table 1: The chemical composition of industrial plant waste, % of dry basis

The type of recyclable material	Polysacharides	Lignin	Mineral (ash) substance
Annual plant waste			
Wheat straw	63,5	19,8	7,8
Sunflower husk	50,6	28,2	2,2
Corncob	66,0-73,4	14,5-18,6	0,9-1,9
Linen awn	53,4	27,0	2,0
Grapevine cuts	60,6	28,3	2,7
Potato vine	51,3	14,1	-
Perennial plant waste			
Chunkwood of cottonwood	66,0	29,3	1,7
Chunkwood of pine	65,7	24,7	0,2
Chunkwood of oak	62,7	27,1	0,9
Chunkwood of maple	63,5	27,1	1,3

Source: Authors' computations

The organic component is mainly represented by polysaccharide components, including cellulose, hemicellulose and lignin. In the ligno-carbohydrate complex of any kind of plant materials, lignin is providing a mechanical function, and is closely associated with hemicelluloses. It acts as a gluing agent of the crystalline chains of cellulose with tissues.

The high content (in some species is above 90%) of energetically important organic substances in the waste of almost all plants in question makes it possible to convert them into high-quality fuel raw materials.

The key energy indicator is the specific low heating value (calorific value) of plant materials was determined in a liquid-type calorimeter B-08MA, that was designed to determine the low heating value of solid, liquid and gaseous fuels (DSTU ISO 1928:2006, 2008).

The results of investigations of individual energy parameters and the elementary composition of various types of annual and perennial plants, as well as waste from their processing, are presented in Table 2.

It should be taking into account that the quality of fuel materials depends not only on the chemical composition, but also on other technological parameters. They include moisture (the critical moisture level varies from 10 to 15%, and for some types of raw materials the limit of moisture content is limited by 7-8%). Thus, low heating value of straw is lower than of dry wood. However, taking into account the usual for air-dry straw moisture within 12%, this figure is higher than that of wood chips.

At the same time, traditional types of fuel materials have rather high bulk volume or volume weight (for example, depending on the deposit the coal's bulk volume is 680-960 kg/m^3, and anthracite's bulk volume is 1500 kg/m^3).

The bulk volume of organic waste is small and is within 60-120 kg/m^3 in a free state, and 180-220 kg/m^3 for placed in a container waste. It also includes vegetable waste which has

Table 2: The main energy characteristics of various types of fuel biomaterials

Sample number	Sample name	Composition of the organic part				Ash, %	S concentration, % towards to oven-dry weight	Caloric value, MJ/kl
		C	H	N	O			
1	Pine (Pinus) softwood	50,4	5,6	0,7	43,3	0,20	0,03	18,5
2	Pine (Pinus)\ hardwood	50,6	5,8	0,9	42,7	0,15	0,03	18,6
3	Oak (Qutrcus) hardwood	50,2	6,1	1,3	42,4	0,90	0,02	19,0
4	Cottonwood (Populus) softwood	51,3	6,0	1,6	41,1	1,70	0,02	18,2
5	Muteia (Cuibourtia arnodiana) hardwood	49,6	6,3	1,8	42,3	0,84	0,01	19,0
6	Appletree (Appletree, Malus) hardwood	50,0	6,1	1,4	42,5	0,75	0,02	18,6
7	Wheat straw	44,0	5,5	0,7	49,8	5,5	0,20	13,12
8	Sunflower husk	50,9	6,2	0,8	42,1	2,2	0,10	15,50
9	Linen awn	50,2	6.1	1,0	42,7	2,0	0,07	13.80
10	Corncob	52,4	6,3	1.2	40,1	1,1	0,05	11,80

Source: Authors' computations

a moisture content about 10-12%. Waste realization of fuel materials with such indicators is unprofitable both from energy and economic point of view (because of their transportation). Therefore, plant materials' and their waste usage in compacted form (in the form of briquettes or pellets) with increased bulk volume up to 600 kg/m^3 and more is technologically and economically viable solution.

In Europe, liquid biofuels for diesel engines of vehicles – bioethanol or biobutanol, as well as biodiesel fuel – have also found widespread use. Bioethanol can be easily obtained from simple water-soluble monosaccharides (from glucose, carbohydrate-containing food waste of beets, potatoes, as well as from cellulosic agricultural waste in the form of straw, seed husks, plant stalks and wood chips by the enzymatic reaction of alcoholic fermentation under anaerobic conditions). In addition to well-known types of yeast, it is possible to use both active groups of bacteria at a temperature of 40 C as an enzyme source, and modified strains which are active at a temperature of 65-75°C and are capable to hydrolyze complex polysaccharide chains to simple sugars from almost all types of organic agricultural waste, forestry, sugar plants (Tigunova et al., 2013). For example, in the USA, 150 liters of ethanol are produced from 1 ton of straw (or old cardboard) after hydrolysis of cellulose and further microbiological digestion of glucose.

It has been established that biobutanol as a fuel is more high-calorie, less volatile, less aggressive and expensive than ethanol (it is in 13.5 times less volatile than gasoline, so it's safer). In addition, biobutanol can be prepared from cheap substrates – recycled carbohydrate materials, and namely syrup, molasses, cellulose hydrolysates and lignin of various plant species. The biotechnological process is carried out by the method of acetone-butyl fermentation with the participation of anaerobic saccharolytic bacteria Clostridium acetobutylicum. A simplified biochemical reaction for the mixture formation of energy products of butanol, acetone and ethanol (on average, their ratio depending on the composition of the substrate varies 60:30:10, respectively), can be represented as an equation:

$$12C_6H_{12}O_6 \xrightarrow{\text{fermentation}} CH_3CH_2(CH_2)_2OH + CH_3COCH_3 + C_2H_5OH + CH_3(CH_2)_2OH + 28CO_2 + 18H_2 + 2H_2O \quad (1)$$

Biobutanol's energy intensity is close to that of gasoline, so it can completely replace it in fuel cells. Biobutanol is more economical than a mixture of gasoline and bioethanol. It improves the fuel efficiency of cars (increases mileage per unit of consumed fuel). Russia is the largest producer and exporter of biobutanol from wood raw materials (developed by the Russian Corporation "Biotechnology). " Over the past 5 years, more than 60% of this type of motor fuel was supplied to external market by the Russian Federation (since 2007 – sale to the UK).

The environmental advantage of liquid biofuels using is that its combustion does not disrupt the balance of carbon distribution in the earth's atmosphere and in the earth's crust (the same amount of carbon dioxide is emitted from the atmosphere for life activity as a result of its combustion). Moreover, biofuels' burning minimizes the emission of harmful exhaust gases into the atmosphere: carbon monoxide, nitrogen and sulfur oxides, residues of unburned hydrocarbons, soot particles, etc.

The US federal government provides liquid biofuel producers with a tax credit of that is up to $ 0.51 per gallon (1 American gal=3.785; 1 English gal=4.546 gal) (Vasilov, 2007a). The European Union plans to provide a quarter of its fuel needs for road transport with clean and efficient biofuels by 2030 (Pantshava, 2015).

Biogas technology is recognized as a rational way of recycled biomaterials' utilization. It has been used since ancient times. It is noted that to solve the environmental problem of organic waste local accumulation, which amount significantly exceeds their biodegradation potential, biogas production processes were used with the participation of the most widespread methanogen archebacterium groups (about 10 types of methane bacteria *Methanococcus* and *Methanobacterium* are known) (Vasilov, 2007b).

The process of methanogenesis can be represented as a simplified reducing biocatalytic reaction:

$$4H_2 + CO_2 \xrightarrow{\text{fermentation}} CH_4 + 2H_2O \quad (2)$$

Biotechnology of biogas production (in other words, mixture of: CH_4–50–75%; CO_2 – up to 25-30 %; insignificant amount [up to 1%] H_2S, N_2, NH_3, O_2, H_2 and CO) from renewable organic waste materials is a complex of multistage enzymatic process. The main factor in the breakdown of solid biomass into individual components and their further conversion to methane are anaerobic conditions and the aquatic environment, since most bacteria are able to consume substances only in dissolved form.

During the chain metabolic mechanism, chemical bonds of biomaterial organic complex are converted into enzymatic reactions products of one group of aerobic bacteria to form nutrients for the other – anaerobes-acetogens, and their further transition into the energy of biogas compounds. The quality of biogas depends on the methane content in it or on the ratio between itself and its carbon dioxide, which dissolves biogas and saves it from losses during storage. High methane's concentration in biogas mixture – more than 50% is provided by the criteria for the quantitative and qualitative composition of the substrate (that is, the optimal concentration of carbohydrates, proteins and lipids in biomass). It depends on the temperature control; hydrogen sulfide amount limiting that causes equipment corrosion, as well as the content of ammonia, elemental nitrogen, sulfur, hydrogen and oxygen, the amount of which may be up to 6-8% in the biogas mixture. It is desirable to enrich a biogas product by drying with condensation of ammonia and water vapor.

An organic substrate is additionally seeded with acetogenic and methanogenic bacteria – mesophiles (withstand temperatures of 30-40°C) to intensify methanogenesis in biogas-fired plants; with thermophiles adapted to the temperature of 30-40°C; with psychrophilia adapted to the temperature – 20°C. The optimal mass ratio of C: N elements is in the range of 11-16: 1 in the substrate. Moreover, nitrogen content increasing leads to ammonia release into the media and its alkalinization. Therefore, it is advisable to add recycled carbon-containing materials (ground straw, sugar beet waste, sugar cane bagasse, etc.) to organic waste with a high nitrogen content.

Since the parameters of technologies in which formation and accumulation of organic wastes have certain differences, it is impossible to create one type bioreactor-fermenter. Design options for biogas plants depend on environmental conditions, the existence of available and inexpensive materials.

In most cases bioreactor is made of reinforced concrete. It allows to save metal consumption, but requires more time and labor costs. Reactor's volume depends on biomass amount that will be processed. New portions of the substrate are continuously loaded into biogas reactor (filling by 90%) to ensure its continued operation, an appropriate amount of product is taken and bacterial degradation of cellulose-containing substrate is activated by automatically temperature maintaining of the coolant – 40 C. Bioreactor in the volume of 50 m^3 can produce 100 m^3 of biogas per day. At that, 300 m^3 of biogas can be obtained from 1 ton of straw, and 130 m^3 from 1 ton of household organic waste.

The pressure of produced biogas is to 100-300 mm w.g. on average equivalent and is sufficient to deliver it over a distance of several hundred meters without gas blowers or compressors using. Bioreactor is carefully heat-insulated (creating a light frame filled with glass wool or applying a layer of polyurethane foam on its surface, etc.) to reduce the heat consumption.

The energy value of artificially produced methane (biogas mixture) in such a bioreactor is 10 kW/m^3, and its composition is similar to natural gas. The heat value of biogas product, including: 60-70% methane, 30-35% carbon dioxide, 2-3% nitrogen, 1-2% hydrogen, up to 1% oxygen, traces of hydrogen sulfide are 20-22 MJ/m^3, and energy of 1 m^3 of such biogas is equivalent to 0.5-0.6 m^3 of natural gas, 0.74 liters of oil, 0.65 liters of diesel fuel, 0.48 liters of gasoline, 3.5 kg of firewood, 12 kg of briquettes from biomass (Pantshava, 2015).

Up to 2.5-3 kW/h of electrical power and 4-5 kW of thermal energy can be obtained by burning of 1 m^3 of biogas (up to 30% of the gas product can be used for technological needs of biogas plant) (Vasilov, 2007b). After biogas is compressed to 15-16 atm., it can be refilled into gas cylinders.

4. THE RESULTS OF RESEARCH

Within the framework of study, it was found that nowadays there are various ways to increase the waste organic mass density. Briquettes and granules or "pellets" (normalized pressed products from waste wood and residual wood, crop waste by-products, etc.) are recognized as one of the most promising areas in energy technologies' development (Svietkina et al., 2017; Mate, 2014). Pellets and briquettes are exclusively made from natural organic raw materials. These fuel materials contain lignin ("natural glue"), so their production does not require additional additives and binder components. The lignin complex of plant cells has a feature to initiate the passage of a chemical reaction in high pressure and temperature conditions, accompanied by structural changes in the material with the acquisition of viscoplastic properties.

Clearly the environmental and economic benefits resulting from the use of different types of fuel can be considered by comparing the levels of air emissions of pollutants without cleaning systems exploitation and their costs per unit of material (Table 3).

According to the data in Table 3, wood fuel (firstly, briquettes and pellets) is more environmentally friendly and preferable in comparison with traditional types of fuel materials. In terms of greenhouse gas emissions (primarily CO_2), it has almost a "zero effect," which is especially important in the context of sustainable development indicators. Economic benefits of biofuel materials using are also obvious.

Thus, fuel types based on biomaterials are not only free from undesirable sulfurous substances in a result of combustion, but also have sufficiently high calorific value, low inorganic impurities, large combustion surface and a high ratio of exotherm to emitted carbon. In this regard, the priority and topical direction is the research, analysis of the main energy characteristics of various waste types and waste biomaterials, and is also the rationale for the ways of their targeted use as an energy resource.

Table 3: Comparative analysis of environmental and economic characteristics of various energy sources

Type of fuel	Pollutant emissions amount into the atmosphere during the energy combustion, tons/thousand tons of fuel					Fuel's cost, rubles/kW per unit of material*
	CO_2	NOx	SO_2	Dispersed solids (soot)	Total	
Natural gas	1,18	3,52	0,00	0,00	4,70	0,56-0,75/м³
Coal, (W=10%)	9,58	63,56	9,20	65,32	147,66	1,57-1,76/кг
Diesel fuel	15,53	29,0	11,18	2,7	58,41	3-4/кг
Wood (firewood), W=10-15%	4,90	9,40	0,30	4,30	18,90	1,36-1,66/кг
Wood waste	5,60	11,40	0,80	13,40	31,30	0,16/кг
Peat briquettes	8,04	26,81	3,00	13,02	50,87	1,8-2,0/кг
Briquettes, wood pellets	4,68	9,31	0,28	4,11	17,69	1,9-2,0/кг
Briquettes, pellets annual plants	3,10	9,50	0,15	1,5	14,25	1,78-1,8/кг
Biogas	-	-	-	0	< 0,001	0,5-0,6/м³
Bioethanol (concentration - 70%/90%)	-	-	-	-	< 0,001	0,97/1,04/л

Source: Authors' computations. *Order of the Ministry of Natural Resources and Ecology of the Russian Federation 300 (2015)

Briquettes and pellets that are produced on impact-mechanical presses or through the usage of extruder technology from previously crushed and heated biomass, according to regulatory requirements, have a high density of 1000-1400 kg/m^3. They are characterized by high calorific value (Table 2) and burning duration. Fuel briquettes and pellets are intended for incineration in furnaces, fireplaces, greenhouses, rail transport, factory boiler rooms and CHP plants, industrial plants, where there are installations operating on solid fuel. This aspect expands their consumer properties at the market.

Thanks to these advantages, fuel briquettes and pellets (Euro-wood) are most prevalent in Denmark, Sweden, Austria, Germany, Norway and Finland. Until 2001, the consumption of these materials in Europe increased annually by an average of 30%. The demand for granules was satisfied by 9% in Germany in the same period. Denmark began to receive half of all generated energy from granulated wood fuel. More than 80% of consumed in Denmark pellets are imported. According to some estimates, Sweden may become the first European country that would be able all in all to switch to alternative energy forms in 15 years.

According to analytical data, the trend of solid biofuels consumption for energy generation is increasing. Abroad, the most serious producing countries (as well as consumers) of pellets and briquettes are: Europe – 3.0 million tons/year; the USA about 2 million tons/year; Canada about 110 thousand tons/year; Japan about 3 thousand tons (Pantshava, 2015).

Russia's fuel and energy complex plays an important role in the country's economy. 1/3 of the world reserves of natural gas, 1/5 of coal, 1/10 of oil is concentrated on its territory. These facts create complacency in public mind and some underestimation of situation (Nazarova et al., 2017a). At the same time, according to the official experts' forecasts, oil production may decrease from 518 million tons (2012) to a level of 1 million tons in Russian Federation by 2020 (Goryainov, 2015).

Thus, the benefits from alternative types of biofuel materials using have integrated nature. Firstly, these are favorable technological properties: high bulk density, the possibility of fully fuel supply automation to the combustion zone, they are not explosive, as well as they are not self-igniting and do not decompose under appropriate storage conditions, there is a possibility of existing equipment employment without upgrading and minimal fireproof rest. Secondly, there are economic advantages: A relatively low price at high calorific value, small storage areas and transportation costs. The ecological aspect is also of great importance and is reflected in renewable biofuels use and the reduction of environmental components pollution.

5. DISCUSSION

Conducted analysis has allowed to establish that searching for new alternative, environmentally friendly substitutes are major aspect now, considering that current problems are associated with traditional types of fuel materials using (minerals exhaustion, energy prices increasing, environmental degradation) (Nazarova et al., 2017b).

It is shown that organic waste, including vegetable waste, which accumulate constantly, create environmental and economic problems and have sufficient energy capacity. In addition, renewable recycled biomaterials use has a number of predominantly complex characteristics: environmental (low emissions from the atmospheric pollutants combustion, including greenhouse gases, waste management); technological (high bulk density, lack of explosion hazard, stability to storage conditions, minimum ash content, etc.); economic (low cost at high calorific value, low transportation costs).

It was emphasized that using of various types of energy sources based on recycled biomaterials (solid fuel, liquid biodiesel, biogas) helps to solve both global problems – greenhouse gas emissions reducing and the risk of acid rain formation decreasing, by lowering of sulfur and nitrogen oxides emitted amount. Local problems, which can be also solved, are connected with large-scale of industrial and agricultural waste disposal, hundreds of thousands of tons of which are annually produced. It is also possible to obtain additional economic benefits from such methods application.

According to experts in energy area, in the next 2-3 decades the growth of energy consumption and production will be about 60% of its global production and consumption at the beginning of the XXI century. Energy production increasing should take place against the background of environmentally friendly energy technologies creation, the creation of new constantly renewable sources of fuel and energy, the complete re-equipment of industry and agricultural production for energy-saving equipment, machinery and technology (Pantshava, 2015).

As noted by many experts, alternative biofuel energy resources using is very reasonable and promising. According to analytical data, the consumption level of solid biofuels will reach 21 million tons/year in Europe by 2020 (Boyarintseva and Popov, 2014).

It is positive that the trend of biofuel materials consumption for energy production in developed and developing countries is increasing, which is confirmed by statistical data and practical experience of many countries around the world. Thus, the use of electricity produced from biomass, is growing particularly rapidly in China and in Europe, namely an average of 8% per year; at the same time, bioethanol production on a global scale increased by 4% and record numbers are observed in the USA (IRENA, 2019).

6. CONCLUSIONS

According to UN experts, the population is projected to increase to 9.2 billion people by 2050. In case of increase in motor fuel and natural gas consumption per capita to the level of the European Union by this time, it will be necessary to produce 18.3 billion tons of oil (that is, 16% of the explored reserves), and natural gas – up to 12 trillion m^3 (6,7% of proven reserves). At the same time, there will be enough oil for 6-10 years, and gas for 15-20 years.

In this regard, using of non-traditional raw materials based on recycled biomaterials of plant origin is relevant and promising for the world economy and energy due to the following factors:

- The experimental data on the chemical composition and energy characteristics of recycled plant biomaterials are indicative of the Rationality of their use for the production of various types of energy resources (dual fuel briquettes, pellets; liquid biofuels: biobutanol, bioethanol; biogas);
- Complex combination of technological, environmental and economic tasks allows not only to control the level of environmental pollution, but also to form technical solutions that reduce environmental risks;
- Directional disposal implementation of accumulated biomass waste;
- Reducing of gaseous emissions amount that pollute the air and pose an environmental hazard to living organisms and nature in general;
- Additional economic effects obtaining by production costs reducing and biofuel materials using.

In general, it is likely that the complete replacement of traditional fuels with alternative sources may not happen in the near future, but the optimal combination of them will provide both positive environmental and economic results. Obviously, recycled biofuel materials using requires further research and selection of rational technological parameters.

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