UDC 662.767.2:628.477.6(477) (045)
DOI https://doi.org/10.32846/2306-9716/2026.eco.6-69.59

EVALUATION OF WASTE-TO-FUEL POTENTIAL IN UKRAINE

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The article discusses the problem of the impact of household waste on the environmental condition of Ukraine, as well as ways to solve it. Today, in the world, in particular in Ukraine, there is a significant danger of the lithosphere, atmosphere and hydrosphere pollution by household and industrial waste. The role of the negative waste impact on the environmental condition of Ukraine in the formation of the degree of environmental hazard hasn't been sufficiently studied. Over the past 100 `years, mankind has increased energy resources more than 1000 times, while increasing the volume of industrial and agricultural products. This, in turn, led to an increase in the amount of waste. The main objectives of the work were to justify the use of household waste as a raw material for alternative fuels in Ukraine and to determine the contribution to the formation of the economic hazard degree due to environmental pollution with solid household waste. The negative impact of waste on Ukraine's environmental condition has been studied. The shortcomings of the actual solid waste disinfection methods were analyzed. The method of household waste processing for the purpose of obtaining alternative energy sources was substantiated. It has been established that the most effective method of reducing emissions of biogas (landfill gas) from solid household waste landfills into the atmosphere was its collection and use. The economic indicators of landfill gas production and recycling projects are quite profitable, especially when the landfill is located close to an industrial gas consumer. The development of technologies for the production and use of landfill gas is very promising for Ukraine from both an environmental and an economic point of view. State regulation in the field of waste processing is of high importance, since it will not only improve the environmental condition of our country, but can also significantly affect the improvement of the energy situation in Ukraine. Research results can be applied in the field of environmental protection. The results of this work can be applied by expert environmentalists, as well as energy engineers and experts in the field of the production and rational use of alternative energy sources.
Key words: environmental safety, waste management, incineration, landfill gas, alternative fuels, catalysts.

Оцінка потенціалу перетворення відходів на паливо в Україні. Трофімов І.Л., Павлюх Л.І., Явнюк А.А., Грушак З.В., Фролов В.Ф.

У статті розгянуто проблему впливу побутових відходів на стан довкілля України, а також шляхи її вирішення. Сьогодні у світі, зокрема в Україні, існує значна небезпека забруднення літосфери, атмосфери та гідросфери побутовими та промисловими відходами. Роль негативного впливу відходів на стан довкілля України у формуванні ступеня екологічної небезпеки вивчена недостатньо. За останні 100 років людство збільшило енергетичні ресурси більш ніж у 1000 разів, одночасно збільшивши обсяги промислової та сільськогосподарської продукції. Це, у свою чергу, призвело до збільшення обсягу відходів. Основними завданнями роботи було обґрунтувати використання побутових відходів як сировини для альтернативного палива в Україні та визначити внесок у формування ступеня економічної небезпеки внаслідок забруднення довкілля твердими побутовими відходами. Досліджено негативний вплив відходів на стан довкілля України. Проаналізовано недоліки сучасних методів знезараження твердих відходів. Обґрунтовано метод перероблення побутових відходів з метою отримання альтернативних джерел енергії. Встановлено, що найефективнішим методом зниження викидів біогазу (звалищного газу) зі звалищ твердих побутових відходів в атмосферу є його збір та використання. Економічні показники проєктів виробництва та перероблення звалищного газу є досить прибутковими, особливо коли звалище розташоване поблизу промислового споживача газу. Розроблення технологій виробництва та використання звалищного газу є надзвичайно перспективним для України як з екологічної, так і з економічної точки зору. Державне регулювання у сфері перероблення відходів має велике значення, оскільки воно не лише покращить екологічний стан нашої країни, але й зможе суттєво вплинути на покращення енергетичної ситуації в Україні. Результати досліджень можуть бути застосовані в галузі охорони навколишнього середовища. Результати цієї роботи можуть бути застосовані експертами-екологами, а також інженерами-енергетиками та експертами у сфері виробництва та раціонального використання альтернативних джерел енергії.
Ключові слова: екологічна безпека, управління відходами, спалювання, звалищний газ, альтернативні види палива, каталізатори.

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Introduction – general statement of the problem and its connection with important practical objectives. During research activity related to the study of the problem of pollution by household waste in industrially developed urban systems, considerable attention was paid to the sources of industrial hazard [1-6].

About 30 tons of natural resources are extracted annually per inhabitant in industrialized countries. Only 2–5% of these resources take the form of a product, the rest end up as waste. In cities with a population of about 20,000 people, about 64 tons of waste are accumulated per day. These waste overflow waste dumps and special landfills. The amount of solid household waste increases annually by 3-6% [7], which significantly exceeds the rate of growth of the Earth's population.

The problem of solid household waste is quite acute for Ukraine [8-13]. The issues of solid household waste management, search for new and improvement of existing methods of waste processing in Ukraine are quite relevant today.

The depletion of oil reserves, increasing oil consumption, and growing environmental pollution have stimulated the development and implementation of alternative fuels, according to energy-efficient development programs of all developed countries of the world [14-17].

According to the long-term observations of human activity by many scientists, in particular in large cities, it was established that the average annual concentrations of harmful substances in the air and soil within household waste dumps exceeded the maximum permissible concentration (MPC) by 1.3-2.5 times.

Analysis of recent research and publications. The author of the article [7] drew attention to the fact that even under conditions of maximum compliance with the requirements of sanitary norms and rules at the regional level (implementation of atmospheric protection measures, use of effective systems for monitoring the condition of atmospheric air, availability of bypass transport highways, landscaping of the territory, etc.) the problem of solid household waste management still remains actual. Such results made it necessary to monitor manifestations of environmental hazards at the level of analysis of specific technological processes of the formation of dangerous factors in order to identify objects that make a significant contribution to the formation of environmental hazards.

The author of the work [18] envisaged the combination of natural and man-made cycles into a single system with the aim of managing these cycles at the expense of objectively existing "buffer" zones or creating technological cycles. To improve the environmental situation, the author proposed improving the municipal solid waste management system.

The author of the work [19] claimed that the problem of solid household waste for 2021 was quite acute for Ukraine. According to data, about 25 billion tons of various waste are accumulated in Ukraine. According to the estimates of European Union experts, 24 million tons of hazardous waste is generated annually. 75% of this waste is stored in landfills. At the same time, the disposal of waste that can be reused in other ways or buried should be considered as inefficient. As an alternative method of handling solid household waste, the author proposed a thermal method of recycling (incineration).

In table 1 statistical data on the accumulation, generation and use of industrial and household waste in Ukraine are presented [20].

In a simplified form, waste generation rate per 1 person is:

– household waste – 1.1 kg/day;
– commercial waste – 0.6 kg/day;
– industrial waste – 1.4 kg/day;
– miscellaneous items waste – 0.1 kg/day;
Total – 3.2 kg/day.

Table 1

Accumulation, generation and use of waste in Ukraine

№	Indicator	Value
Industrial waste		
1	Accumulation: total, billion tons per person, tons per 1 km^2, thousand tons	30 600 50
2	Total area, thousand ha	200
3	Formation, million tons / year	700–710
4	Waste disposal, %	10–15
Solid household waste		
5	Accumulation: total, billion m^3 per person, tons (m^3) per 1 km^2, thousand tons (thousand m^3)	3–4 17 (76) 1,3 (6)
6	Authorized landfills, pcs.	771
7	Generation of solid household waste, million tons / year	10–11
8	Increase in production, thousand tons / year (% / year)	130–200 (1,3–2,0)
9	Use of household waste, %	2–5

The author of the work [21] cited data that the amount of household waste in European countries was about 38–40 million m^3 every year (or about 10 million tons). Ukraine is not far behind the average European statistics.

The average composition of household waste in Ukraine in percentages is approximately as follows [6]: cellulose-containing materials (paper, cardboard, newspapers, wrappers, packaging, etc.) – 30–35; food waste – 28–30; metals – 4; plastic – 4; wood – 3; textiles – 5; glass, ceramics – 7; other – 10–12. The share of waste with an organic component is 70–78%.

According to [22] the total amount of waste generated by a person in 2020 was estimated as 11.1 tons. This value was twice greater compared to the waste generation in Europe, where this rate was 4.8 tons. Nowadays, this problem remains relevant. In general, the total mass of this waste all over the country reaches 13 million tons per year, and this amount is growing exponentially.

 ISSN: 2306-9716 (Print), ISSN: 2664-6110 (Online)

Moreover, among solid household waste, the share of waste that does not undergo rapid decomposition and requires significant areas for storage is rising also.

It is known that the formation of biomass (cell growth) is caused by the production of carbon in plant cells due to photosynthesis. Every year due to photosynthesis, such an amount of biomass is formed that its dry residue is equivalent to 220 billion tons, which exceeds the world's need for fuel by approximately 10 times.

Hence, solid hydrocarbon industrial and household waste, which make up about half of all solid waste in Ukraine, are also to be considered as a secondary raw material. Significant reserves of this raw material have high energetic and chemical potential and can be utilized more completely and efficiently from an economic perspective. The author of the paper [23] estimated that the country's economy had lost 3.3 million tons of waste paper, 550 thousand tons of metals, 660 thousand tons of polymers, 770 thousand tons of glass, and 550 thousand tons of textiles every year. The city could save 8,250 tons of valuable raw materials per year due to the use of household waste.

The author of the work [24] expresses the opinion that burning garbage is dangerous for the environment, because dioxins, furans, biphenyls, other harmful substances and a large amount of dust are released into the atmosphere. Dioxins destroy the human hormonal system, lead to immunodeficiency and weakening of the body's defenses, contribute to the development of women's diseases, and increase the number of miscarriages and disabled children. Waste incineration plants are considered as one of the main sources of dioxin formation. Public opinion on waste incineration is strongly negative.

Today, in world practice, there are 2 most widespread methods of recycling of solid household waste: incineration at specialized plants and burial at natural or sanitary landfills [25, 26]. Each of these methods has its own shortcomings, which significantly affect the environmental condition in the country. This condition can already be considered as a crisis due to the huge amount of harmful substances released into the atmosphere, soil, and water through emissions from transport and industry.

Highlighting previously unresolved parts of the general problem to which the specified article is devoted. Therefore, the actual methods of waste processing in Ukraine do not meet modern environmental requirements, so today the search for alternative ways to solve this problem is quite relevant. Waste is a secondary raw material and has great energy potential, thus alternative energy carriers may be obtained from it via alternative processing technologies, which in turn will help partially solve the energy problem in our country.

The analysis of references devoted to the assessment of the impact of household waste on the environmental condition of Ukraine and the management of solid household waste shows that there is no solution to this problem in the scientific literature. Therefore, the relevance of the work is determined by the insufficient data on a specific method of effective processing of household waste.

The amount of biogas collected makes it possible to install a gas power plant with a 1,500 kW total capacity at the landfill. In this case, biogas is produced in special reactors – methane tanks, equipped and regulated in such a way as to ensure maximum release of methane. The energy obtained by burning biogas can reach from 60% to 90% of the energy of the original matter. If the reactor is operating normally, the resulting biogas contains 60–85% methane, 30–40% carbon dioxide, a small amount of hydrogen sulfide (0–3%), and a mixture of hydrogen, ammonia, and nitrous oxide.

Biogas obtained during fermentation does not have an unpleasant smell, its lower calorific value is 25 MJ / m^3. Biogas has a calorific value of 5340–6230 kcal/kg (6.21–7.24 kW/kg). The output of biogas is 0.2–0.4 m^3 per 1 kg of fermentable dry matter at the consumption of 50 kg of dry biomass per 1 m^3 of water. It is known that 1 m^3 of biogas is equivalent to: 0.6 m^3 of natural gas, 0.7 liters of fuel oil, 0.4 l of gasoline, 3.5 kg of firewood, 12 kg of manure briquettes. 1.7 kW · h of electricity and 2.5 kW of heat, can be obtained from 1 m^3 of biogas while up to 30% of biogas is used for the technological needs of the installation. After biogas is compressed to 15–16 kg/cm^2, it can be used to fill cylinders [26].

From an environmental perspective, the utilization of landfill biogas for energy production is particularly important, since one of the main disadvantages of alternative energy sources is the instability and limited controllability of energy generation. Unfortunately, a person cannot intervene in the anaerobic processes that occur inside the layer of accumulated waste. One can only try to ensure the necessary composition of solid household waste entering the landfill, as well as to organize effective technologies for capturing the produced biogas. The required composition of waste shall be achieved via the introduction of systems for the separate collection of solid household waste, in which most of the components that do not decompose biologically are sent for secondary disposal. On the one hand, such systems reduce the consumption of primary natural resources. On the other hand, the share of methane-producing waste (food residues) is increasing in the waste sent to the landfill. Technologies for capturing the generated biogas involve the development of efficient systems of pipelines and wells that cover the entire area of buried waste, as well as the creation of systems for isolating the surface of the landfill, which prevents biogas release to the atmosphere.

In our opinion, the collection and use of biogas (landfill gas) from solid household waste landfills, taking into account also the problem with energy resources, is one of the most profitable methods for Ukraine today, but it is not the only one. Also, as an option, we offer to place facilities for the production of catalysts for exhaust gases treatment at the sites of solid household waste landfills. As is known, catalysts for treatment of exhaust gases

of automobiles [27-30] are made from sludges – waste products of the metallurgical, electronic, and machinery industries, which contain oxides of Copper, Iron, Chromium, Nickel, Manganese, Cobalt, and other metals. But the analysis of the sources showed that solid household waste also contains the same substances. The specified oxides are in the slurry in a highly dispersed condition. By adding inorganic impurities to them with certain processing, it is possible to obtain these catalysts. They make it possible to treat car exhaust gases from CO_2 to 6–0% and thus protect the atmospheric air.

In recent years household and industrial waste is also considered as promising raw materials for the production of aviation biofuels [31]. Currently plants are being actively built where the waste of the following types is processed into the fuel as a result of complex technological processes: wood products, paper, woodworking residues, agricultural waste, livestock by-products, some industrial waste, food and household waste, municipal sewage and some others. One of the advantages of this use of waste is the opportunity to ensure the production of biofuels from vegetable raw materials without waste. In addition, processing waste into alternative fuels, according to scientists [18, 32], is a way to solve the problem of waste disposal accumulated in landfills.

Biomass-to-liquid technology is another widely accepted method for producing aviation fuel biocomponents. In principle, this technology is similar to the process of production of synthetic aviation kerosene by the Fisher-Tropsch-synthesis method from lignite or hard coal and natural gas [18]. Various types of biomass can be used as raw materials, such as wood waste, straw, plant residues, etc. At the initial stage, the raw material undergoes splitting at high temperatures – pyrolysis. In the future, synthesis gas is to be obtained from the obtained liquid mass, which is the basis of the Fisher-Tropsch process. It is noted in the works that kerosene obtained by biomass to liquid technology is completely synthetic and its properties are similar to fuel for turbojet engines obtained from coal.

The purpose of the study. The purpose of the study was to justify the use of household waste as a raw material for alternative fuels in Ukraine and to establish the contribution to the formation of the economic hazard degree by solid household waste as an environmental pollution source.

The main part. There are many reasons to believe that waste incineration technologies are dead ends. Currently, the cost of burning 1 kg of garbage is 65 cents. If we do not switch to other waste disposal technologies, costs will increase. In addition, recently in Europe, the pressure of the "green public" on waste incineration plants has increased significantly. Garbage incineration does not contribute to the development of recycling systems, moreover, incinerators are not interested in them. In furnaces, organic matter and polymers are primarily burned, and the extraction of these components from the waste mass makes waste incineration unprofitable. Slag and ash produced during waste incineration, which constitute about 30% of the initial mass of solid household waste, should still be buried in landfills. Today incinerators in Ukraine try not to do this, instead they use the above-mentioned materials in the construction and road repair industry. However, more and more national regulations include ash and slag in the list of hazardous wastes, with corresponding disposal rates and costs. Unlike Western European countries, this method has not become widespread in Ukraine.

Moreover, the energy generated during combustion must be utilized in order to obtain steam or electricity. Such patterns are effectively implemented and functioning in China [25] and the countries of the European Union [33]. Unfortunately, such patterns have not been implemented in Ukraine yet.

At the same time, the number of overloaded landfills is constantly rising, and some of these landfills, unfortunately, do not meet environmental safety standards. Today the number of waste dumps and landfills in Ukraine is about 4.5 thousand, however, there is another problem – illegal landfills, the number of which exceeds 35 thousand. Among European countries, Ukraine ranks first in terms of the level of harmful effects of landfills on the environment.

It is worth noting that today the quality of the incinerating facilities operation is constantly deteriorating: due to the growth of the price of gas required for waste incineration, they are trying to save it. As a result of it, garbage is not incinerated to the slag consistency. In fact, the final product of incineration is burnt garbage instead of ash and slag. In general, the activities of domestic waste incineration plants are officially recognized as dangerous. In addition, expensive natural gas and electricity make the activities of domestic enterprises unprofitable. Their closure is considered a matter of time, and only the lack of funds for alternative methods of waste management is the reason that the incinerating facilities are still operating.

Today it is widely believed that the disposal of solid waste in special landfills is a more economical and universal method than incineration, and in some countries solid waste is mainly sent to landfills. Thus, the amount of solid household waste buried in waste dumps and landfills is 45–55% in the Netherlands, 62–85% in the USA, and 93–96% in Canada.

In Ukraine waste is disposed of at 771 official municipal landfills covering an area of over 250,000 hectares [23]. The vast majority of landfills (80–90%) operate in an overloaded mode, with long-term violation of the design indicators regarding the amount of waste received, without compliance with precautionary measures for the pollution of groundwater and the air pool.

The preparation of a modern solid waste landfill includes sealing and waterproofing the bottom, equipping of the drainage system for the removal of filtered water, and the laying of pipes for the collection of the generated biogas. Buried garbage is covered with layers of sand and clay. When closing a landfill, the thickness

of the sealing layer of soil is usually about 0.5 m. In most developed countries sewage sludge after preliminary dewatering is disposed of together with solid household waste. But this practice appeared only in the last decades and is not carried out in Ukraine due to insufficient funding of this industry.

The disposal of solid household waste in landfills is associated with environmental problems: pollution of groundwater, unpleasant odors, and the development of pathogenic microorganisms. But one of the main problems associated with burying waste is the formation of biogas or so-called landfill gas, the components of which are methane (CH_4) and carbon dioxide (CO_2) in approximately equal proportions. Biogas inevitably enters the atmosphere, it causes many negative consequences. There are many known cases of poisoning during the maintenance of buried engineering communications. Accumulation of gas inside the landfill often causes self-ignition of solid household waste. The burning process is accompanied by the formation of toxic substances, in particular dioxins [20]. The global emission of landfill methane is 40 million tons per year, which exceeds the mass of methane emitted by coal mines and is the main source of the planet's greenhouse gases. Also landfill gas contributes to the emergence of explosive and fire-hazardous conditions both at the landfills and at nearby objects. A great danger is the leachate that penetrates from the landfill area into underground waters and can bring typhoid fever, dysentery, cholera, tuberculosis and other dangerous diseases. Also, large areas of land are alienated for landfills, which are practically impossible to be used after landfill conservation.

So, today, waste incineration and burial technologies have no future, as they do not solve any of the two main problems in the world – the environmental and energetic problems.

It is logical to conclude that the most effective method to reduce the release of methane into the atmosphere from solid household waste landfills is its collection and use.

As is known, the process of biogas formation occurs during anaerobic fermentation of organic substances (at the oxygen lack) and consists of two stages. At the first stage, complex organic polymers (cells, proteins, fats, etc.) are decomposed into simpler compounds due to anaerobic bacteria of various types: volatile fatty acids, lower alcohols, hydrogen and carbon monoxide, acetic and formic acids, methyl alcohol. In the second stage bacteria convert organic acids into methane, carbon dioxide and water.

In recent years, biogas collection and utilization systems at solid household waste landfills have become quite widespread in the world. According to the European Biogas Association, the number of such systems in 2016 was: in Germany – 409, Italy – 89, Sweden – 83, Denmark – 17, the USA – about 1,000. About a third of landfills use biogas to obtain thermal or electrical energy.

Biogas from landfills has high prospective as a sustainable energy source [34-37], as well as from the point of view of the climate change problem solving [37].

Today, in the developed countries of the world, landfills and solid waste landfills of millionaire cities attract considerable attention as a source for biogas production. The main factors in the selection of such sources are population density and time. The influence of the first factor is that the greater the concentration of population in the city, the greater the amount of waste will be produced, therefore, the greater the capacity of landfills receiving this waste. The time factor is that a unit mass of solid household waste placed in a landfill can produce methane for 20-25 years. Therefore, landfills of relatively small cities, which have been operated for a long time, will also have a significant energy potential.

In European countries the connection between the volume of solid household waste landfills and population density tends to decrease due to household waste transportation over fairly long distances (tens and hundreds of kilometers). From the point of view of biogas production, the creation of landfills of such a large volume of solid household waste is promising. However, from the point of view of consumption of produced energy, this is a negative factor, because such centralized landfills are designed at a significant distance from populated areas. However, it is known that for the successful implementation of the bioenergy project based on biogas from solid household waste landfills, the presence of an energy consumer (especially heat consumer) near the landfill is a mandatory condition. Hereby, such consumers are often designed within the framework of energy projects (for example, greenhouses for growing flowers). According to domestic experts, it is advisable to transport landfill biogas at a distance of about 3 km from the landfill. Another way out is the creation of energy projects for the production of only electrical energy, but such projects are less profitable – thermal energy is still produced, but not consumed.

The main conclusions and prospects for the research results application. An assessment of the impact of the solid household waste on the environmental condition was done, and the problem of the waste landfills management in Ukraine and the world was analyzed. It has been established that today the incineration and burial of solid household waste are inefficient technologies, as they do not solve the country's energetic problem, because they do not make it possible to obtain alternative sources of energy from waste, and also affect the environmental condition of Ukraine due to polluting the atmosphere and water with dioxins and other harmful substances.

As a result, it is substantiated that the most effective method for Ukraine today is the collection and use of biogas (landfill gas) from solid household waste landfills and the production of synthetic liquid fuels for cars and aviation from them. The economic indicators of landfill gas production and utilization projects are quite profitable, especially if the landfill is located close to an industrial gas consumer. The elaborating of technologies for the extrac-

tion and use of landfill gas is very promising for Ukraine from both an environmental and an economic points of view, and the truth is that state regulation in the field of waste processing is necessary, as it will not only improve the environmental condition of our country, but shall also significantly improve energy situation in Ukraine.

The problem of solid household waste management in Ukraine needs to be solved comprehensively, using modern global technological methods and tools. For example, in parallel with the collection and use of landfill gas from solid household waste landfills, facilities for the production of catalysts for the treatment of exhaust gases should be placed at the sites of waste landfills. Such a comprehensive approach will help improve the environmental situation in the country and facilitate the implementation and use of alternative energy sources.

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Дата першого надходження статті до видання: 30.09.2026
Дата прийняття статті до друку після рецензування: 04.11.2026
Дата публікації (оприлюднення) статті: 23.11.2026