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Combined solution to problems of increasing the efficiency of engineering systems of power supply and waste management

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Introduction. In modern conditions of economic development of society, technological complexes are used to obtain thermal energy, which is then converted into other types of energy, depending on the purpose of the engineering power supply system. They mainly use various types of organic and hydrocarbon fuels as an energy source. At the same time, along with the increasing demand of mankind for energy, there is a significant increase in the formation and accumulation of production and consumption waste, among which the largest volume is accounted for solid municipal solid waste (MSW).

Problem Statement. The purpose of this study is to provide a possibility for solving the problems of increasing energy production and improving the environmental efficiency of the MSW management system by formulating a scientific hypothesis and scientific approaches based on the main provisions of the theory of dispersed systems and considering MSW as a set of dispersed systems that have a certain amount of energy, and therefore, calorific value. Based on this approach, it is necessary to improve technologies for recycling MSW in order to extract the maximum amount of various types of energy from them.

Theoretical Part. The proposed fundamentally new scientific approach, based on the energy classification of certain types of waste in MSW, as well as energy indexing of technologies for their utilization, allows us to improve the modern system for handling MSW, based on the conditions for extracting the maximum possible amount of different types of energy from waste and ensuring a minimum (within the established standards) negative impact of waste on the environment.

Conclusions. The scientific hypothesis proposed by the authors is based on the fact that MSW can be used as a fuel that has a certain, very significant energy reserve. The authors plan further scientific research related to the identification, formalization and proof of certain patterns described as assumptions, which in the future will allow generalizing the scientific approach proposed for MSW to almost all other types of waste, which for a number of reasons cannot be recycled and reused.

Keywords: engineering systems of power supply, municipal solid waste (MSW), calorific value, MSW handling systems, energy classification of MSW, energy indexing of MSW utilization technologies.

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Introduction. One of the fundamental foundations of the development of the world economy is energy, the main task of which is to produce and transfer to consumers various types of energy (mainly thermal, electric, mechanical) to ensure the intensive development of all spheres of life of the world community [1-3]. At the same time, the main technological element of energy is engineering systems of energy supply, which are technological complexes that provide, firstly, the extraction of energy from various types of fuel (solid, liquid, gas) with its subsequent conversion, or the conversion of one type of energy of natural phenomena, processes and factors into another type, and, secondly, the transportation of the produced energy to consumers. Thus, an engineering power supply system is a set of generating, converting and transmitting power plants that provide consumers with all the necessary types of energy for its use in production and life processes.

In the world practice and in Russia, such engineering systems of power supply include (table 1, fig. 1):

— technological complexes that use various types of organic and hydrocarbon fuels (peat, coal, oil, gas, etc.) as a source of energy — boilers, thermal power plants (TPP), state district power plants (SDPP), thermoelectric power station (TPS), [4];

— technological complexes that use nuclear fuel as an energy source (weakly enriched or unenriched natural uranium, a mixture of uranium with plutonium (Mixed-Oxide fuel)) in the form of fuel elements (fuel rods) — nuclear power plants (NPP) [5, 6];

— technological complexes that use wind flow as a source of energy — wind power plants (WPP);

— technological complexes that use solar radiation as an energy source — solar power plants (SPP);

— technological complexes that use the heat of the Earth's interior as an energy source — low energy stations (geothermal power station);

— technological complexes that use water flows as a source of energy — hydroelectric installations (HI), hydroelectric power plants (HPP), tidal power plants (TPS), wave power plants (WPS);

— technological complexes that use as a source of energy by-products (waste) of agricultural production, processing and food industry-biogas plants (BGP).

Table 1

Main energy sources and engineering power supply systems

Energy source	Type of energy source	Energy conversion technology	Type of engineering power supply system
Fuel	Coal, peat, oil, gas, waste	Incineration	Boilers, TPP, SDPP, TPS
	Nuclear fuel: ^{233}U, ^{235}U, ^{239}Pu	Nuclear decay	NPP
	Nuclear fusion	Nuclear fusion	Nuclear fusion plants
Natural processes and phenomena	Movement of air in the atmosphere	Wind	WPP
	Solar radiation	Photoelectric effect, heat-exchange	SPP
	Geothermal heat of the Earth	Underground geothermal heat exchange	GPS
	River and sea currents, waves, tides	Movement of the water environment	HI, HPP, TPS, WPS
	By-products and waste of plants and animals	Biological processes	BGP

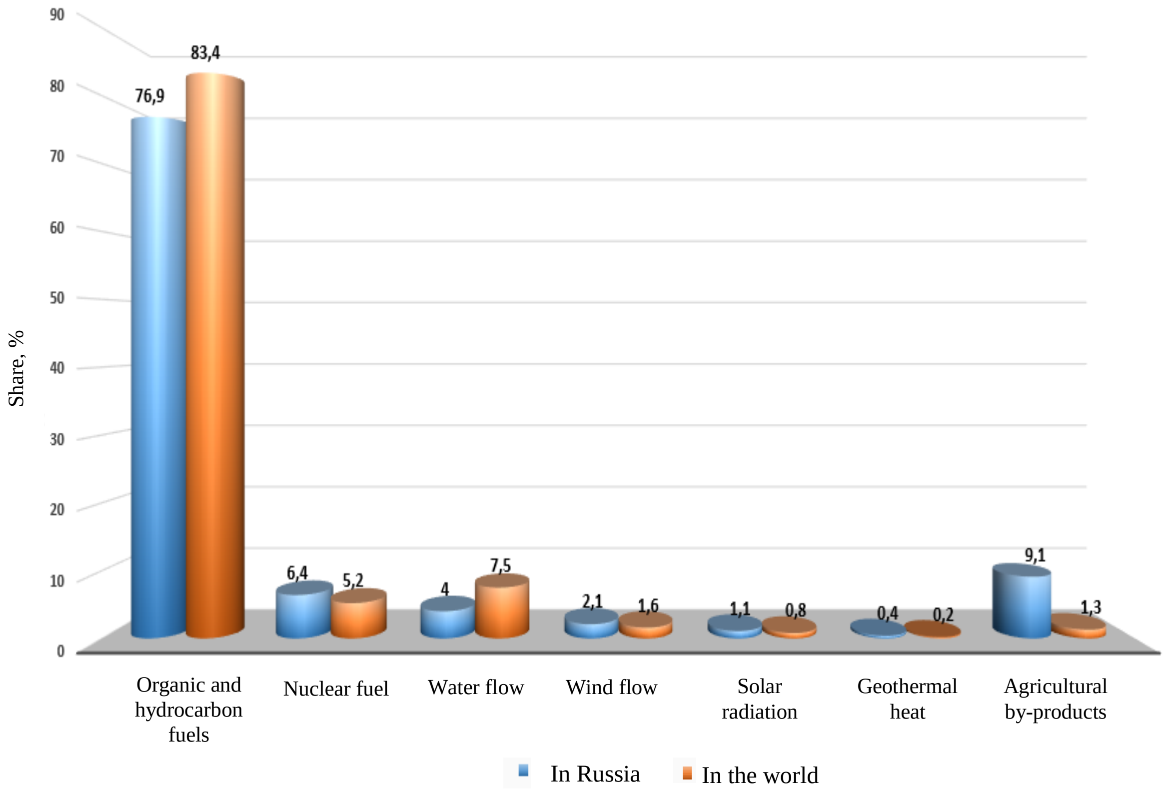

Fig. 1. Use of different types of energy sources in the world and in Russia

The analysis of the scale of application of these technological complexes in the world energy sector and in Russia allows us to conclude that the most widely used in modern conditions of economic development of society are technological complexes [4] that use various types of organic and hydrocarbon fuels as an energy source.

Technological structure of such power complexes, which are engineering systems of power supply, includes the following main units (Fig. 2):

- unit (I) for storage, preparation and supply of fuel to the combustion zone;
- unit (II) for fuel combustion and heat generation;
- unit (III) for converting heat energy to other types of heat (mechanical, electrical);
- unit (IV) for transportation of the produced types of energy (heat, electricity) to consumers;
- unit (V) for auxiliary technological processes that ensure reliable, uninterrupted, efficient, and safe operation of the entire energy complex.

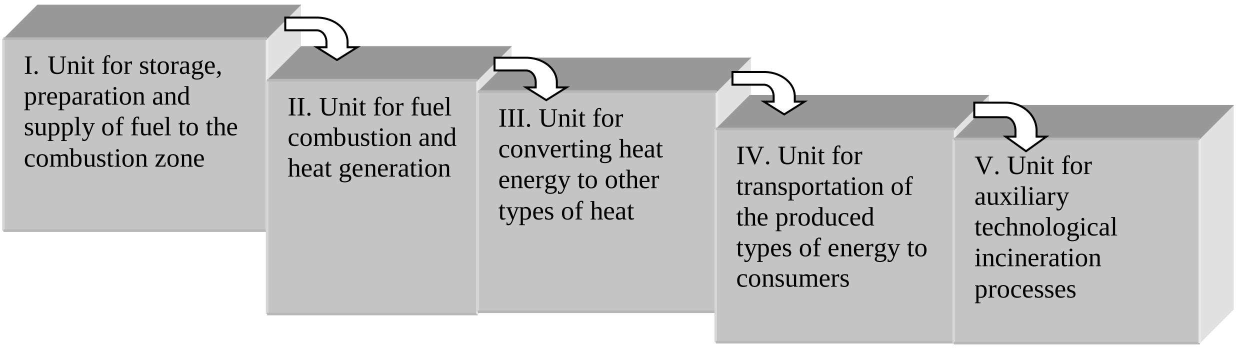

Fig. 2. Technological structure of power supply engineering systems

However, at present, in addition to thermal (combustion) technology, other technologies for obtaining energy from matter are known: exothermic chemical, photochemical, biological, and others. However, in the energy complexes described above, as the main technological process for extracting energy from fuel, a thermal process (the process of burning fuel) is used to obtain, first of all, thermal energy, which can then, depending on the purpose of a specific engineering power supply system, be converted into other types of energy (for example, mechanical and electrical) [7]. In this case, one of the most important characteristics of fuel in terms of the possibility of obtaining energy is its calorific value (J/kg, J/m^3, J/l), characterized by the amount of heat (J) released when the fuel is completely burned with a mass of 1 kg or a volume of 1 m^3 (1 l) (Fig. 3) [8, 9].

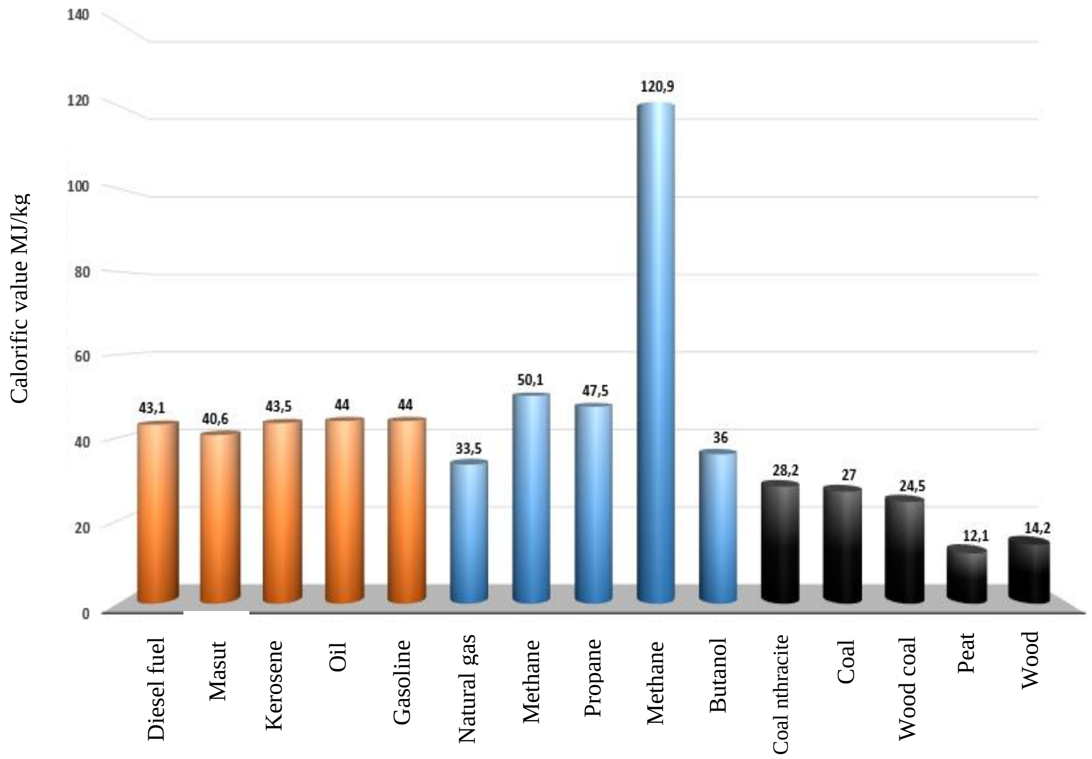

Fig. 3. Calorific value of various types of fuel

High values of calorific value of organic and hydrocarbon fuels explain the most widespread use in the energy sector of technological complexes that implement the process of burning this fuel [10].

Problem Statement. Despite the intensive development of world energy, in modern economic conditions, many countries are experiencing a constant shortage of production of various types of energy. In this regard, the problem of steady growth in energy production remains very relevant.

Along with the increasing demand of mankind for energy and the need for further development of energy in modern conditions, there is a significant increase in the formation and accumulation of production and consumption waste, among which the largest volume is accounted for solid municipal waste (MSW) [11]. The problem of handling MSW is directly related to the possibility of an environmental hazard at the international level and can lead to significant environmental pollution if it is not promptly removed and neutralized. At the same time, the organization of MSW management systems is becoming more complicated every year, due to the constant increase in the mass (volume) of waste generated, the transformation of its composition and properties, as well as the lack of economic resources in many countries necessary for effective processing of the bulk of MSW and recycling of its residue.

Theoretical Part. That is why in modern conditions in Russia and in many other countries, at the state level special attention is paid to significantly improving the efficiency of the MSW management system based on improving technologies for its collection, accumulation, transportation, sorting, processing and utilization [12, 13].

The structure of the MSW management system implemented in modern conditions by many countries is quite effective from the point of view of ensuring the environmental safety of territories, and involves the implementation of the following main stages (Fig. 4):

- separate collection and accumulation of MSW, both "internal" (inside premises, buildings, structures) and "external" (outside premises, buildings, structures);
- separate transportation of MSW to the places of processing and sorting;
- additional sorting of MSW by morphological characteristics, dividing the volume of MSW to be further processed and the remaining volume of MSW to be further disposed of;
- additional separate transportation of MSW to processing sites;
- processing of the main volume of MSW by type, depending on morphological characteristics;
- collection and accumulation of the residue of MSW;
- additional sorting of the MSW residue by type, depending on morphological characteristics;
- additional separate transportation of MSW residue to disposal sites by type, depending on morphological characteristics;
- disposal of the remaining MSW, based primarily on its incineration.

This structure of the MSW management system allows sending up to 90-95% of waste for recycling and reuse, and only 5-10% of waste is subject to further recycling [14]. However, on a global scale, even this 5-10% constitutes an incredibly huge amount of waste, expressed in its mass or volume.

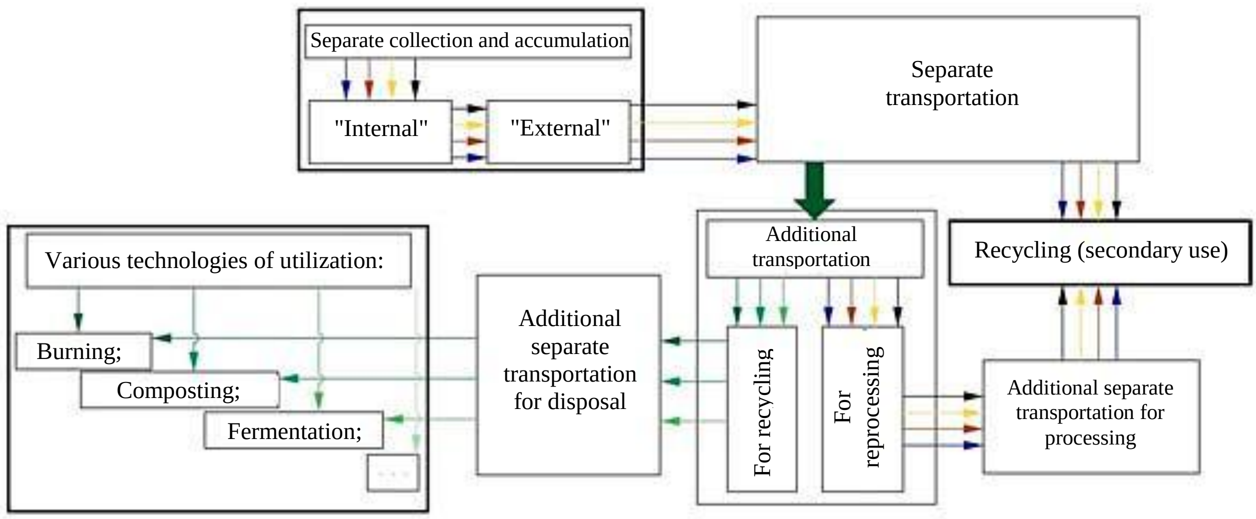

Fig. 4. Structure of modern environmentally efficient MSW management systems

Considering the negative impact of the MSW management system on the environment, it can be concluded that the final stage — the disposal of the MSW residue makes the greatest contribution to the pollution of almost all the main components of the environment (atmosphere, water bodies and soil). In the world practice, various technologies for recycling MSW are used, based on the implementation of various physical, chemical, and biological processes: burial (storage in soil), incineration at different temperatures, composting (decomposition, biodegradation), fermentation, and others. In Fig. 4, waste, starting from the "additional sorting" stage, is separated by morphological features and sent for disposal by appropriate technologies (marked in green).

During a certain historical period, many countries used landfills as the main technology for MSW recycling. However, at present, most countries, having abandoned landfills, use incineration technology as the most effective from the environmental point of view.

The need to solve these two problems together led the authors to choose the directions for further research and formulate a scientific hypothesis, which is in:

- considering MSW as a set of dispersed systems that have a certain amount of energy, and, consequently, calorific value;

- considering each type of waste in MSW as a fuel characterized by a corresponding range of calorific values;

- classification of waste in MSW by groups according to the values of calorific value;

- classification of physical, chemical, biological and other waste management technologies in MSW, based on the capabilities of these technologies for extracting the maximum amount of various types of energy from waste;

- improving the structure of the modern MSW management system based on:

* inclusion of the stage associated with additional sorting of the MSW residue, but not by types, depending on morphological characteristics (as is currently accepted), but by groups, depending on the values of calorific value;

* choosing a recycling technology that will be optimal for the conditions for extracting the maximum amount of various types of energy from the waste of the selected group (in terms of calorific value).

Let us consider in more detail the main provisions of the proposed scientific hypothesis.

The proposed scientific hypothesis and a new scientific approach are based on the main provisions of physical and colloid chemistry, primarily on the theory of dispersed systems [15, 16], according to which any matter can be considered as a dispersed system. A characteristic feature of the dispersed system is the determining role of surface phenomena, since the interface of the phase components is quite large and represents a field of interphase interactions. According to this theory, MSW is a polydisperse system consisting of several solid dispersed phases (separate MSW fractions) and a gaseous dispersion medium (air layers between MSW fractions).

If MSW can be considered as a fuel, then its energy parameters can also be estimated by calorific value. And as some examples of world practice show, MSW may well serve as fuel, having sufficiently high values of calorific value (Table 2).

Table 2

Physical characteristics of certain types of waste in MSW

Examples of waste types	Moisture, %	Solidity, kg/m^3	Calorific value (specific lower heat of combustion), MJ/kg
Food waste of plant origin	60	80	3.43
Food waste of animal origin	75	170	6.21
Paper	25	130	11.49
Tree	5–20	150–160	14.46
Polyethylene film	8	75	23.37
PET bottles	8	27	
PVC bottles	8	54	
Textile	20	85	15.72
Skin	5	65	25.79
Rubber	0,75	160	

Since the calorific value (specific heat of combustion) of each type of waste considered as a fuel depends on the amount of combustible components and varies over a fairly wide range, it can be proposed to classify waste into groups (Table 3) in accordance with the calorific value.

Table 3

Energy classification of MSW groups by their calorific value

MSW group	Range of calorific value values, MJ/kg	Examples of waste types
1	less than 5	Food waste of plant origin
2	5–10	Food waste of animal origin
3	10–20	Paper, textiles, wood
4	more than 20	Leather, rubber, plastic film, PET and PVC bottles

Along with the energy classification of waste groups, the authors proposed energy indexing (classification) of waste disposal technologies in MSW, based on the capabilities of these technologies for extracting the maximum amount of various types of energy from waste. In this case, each technology can be assigned a corresponding index (Table 4).

Table 4

Energy indexation (classification) of waste disposal technologies in MSW by the amount of extracted energy

Index of recycling technology	Range of values of derived energy, MJ/kg	Type of recycling technology
1	less than 5	Biological
2	5–10	Chemical
3	10–20	Thermal low-temperature
4	more than 20	Thermal high temperature

Ultimately, the choice of the optimal recycling technology should be based on the conditions for extracting the maximum amount of various types of energy from the waste of the selected group (in terms of calorific value). The number of the waste group must correspond to the index of the waste disposal technology. Then the structure of the MSW management system (Fig. 4), taking into account the proposed scientific hypothesis and scientific provisions, can be transformed in relation to the appropriate waste disposal technologies (Fig. 5).

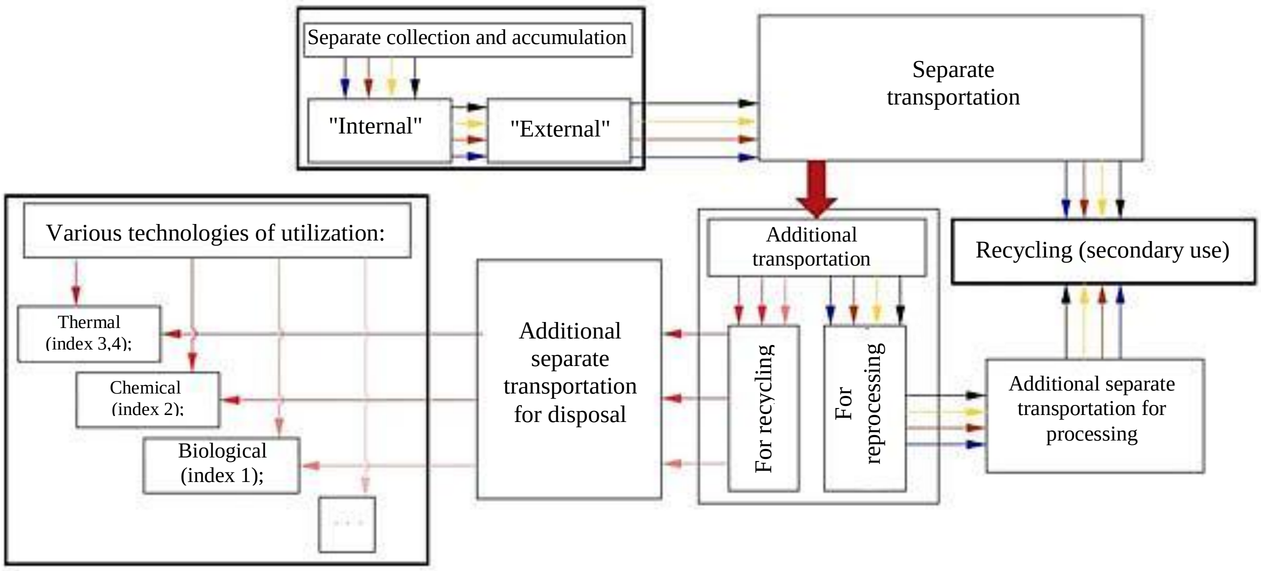

Fig. 5. Structure of the proposed by the authors environmentally efficient and energy-efficient MSW management system

Thus, unlike the structure shown in Fig. 4, starting with the "additional sorting" waste is proposed to divide not by morphological characteristics, but by calorific values in accordance with the assigned group number of waste, and direct disposal technologies, with appropriate indexes (red color in Fig. 5).

Conclusion. Thus, the proposed scientific hypothesis is based on the fact that MSW can be used as a fuel that has a certain, very significant energy reserve. A fundamentally new scientific approach, proposed by the authors and based on the energy classification of both individual types of waste in MSW, and on the energy indexation of technologies for their utilization, allows us to improve the modern system for handling MSW, based on the conditions for extracting the maximum possible amount of different types of energy from waste and ensuring a minimum (within the established standards) negative impact of waste on the environment.

It should also be noted that further scientific research planned by the authors, related to the identification, formalization and proof of certain laws described as assumptions, will allow us in the future to generalize the scientific approach proposed for MSW to almost all other types of waste, which for a number of reasons cannot be recycled and reused.

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V. I. Bespalov — scientific supervision and formation of the main concept, formation of the purpose and objectives of the research; O. S. Gurova — analysis of research results, revision of the text, correction of conclusions; O. N. Paramonova — preparation of the text, drawings, formation of conclusions.