Planning organization of facilities for the municipal solid waste processing for use in the structure of small cities of Russia

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Abstract  The range of problems, related to the environmentally dangerous accumulation of solid domestic waste (SDW) in Russian cities and settlements and the lack of effective ways of handling them, has been analyzed. The importance of this problem is substantiated for the difficult location conditions of geographically remote small towns and settlements of Russia, where the rational solution for solid waste collection conditions, transportation and processing still has not been found. The planning organization concept for small cities with the inclusion in their structure a modern system of objects for processing solid waste is proposed. A new methodological approach to the formation of functionally completed and environmentally friendly small residential agglomerations in the Russian regions is substantiated. The proposed methodology is focused on the use of advanced native technologies, using domestic waste as a renewable source of fuel for the production of electric and thermal energy. The new methodological approach is based on the complete exclusion of domestic waste landfill disposal in small towns in Russia and provides an effective scheme for waste collecting, advance preparation and container delivery for it complex processing with extensive use of the local railway transport network. The results of the study allow us to identify new directions in the field of small towns design and development in Russia, in relation to the requirements of a sustainable ecological environment ensuring.

1. Introduction

For the Russian Federation territories, that are unique in size, as part of its large and small towns, the problem of environmentally hazardous solid domestic waste (SDW) uncontrolled accumulation and open storage has not yet been resolved effectively. According to supervisory authorities, more than 35 million tons of municipal solid waste are generated annually in Russia, generated mainly in the residential sector. More than 90% of the waste is currently stored in its original state and stored in open landfills with a total area of more than 150.0 thousand hectares. At the same time, a feature of waste management is their collection and transportation to storage sites in the original unsorted form. Most of these wastes are characterized by complex morphological, polluted composition, high humidity, and the presence of toxic chemical and organochlorine compounds [1]. Maintaining this situation raises the issue of a stable negative impact on the sanitary state of the environment and living...
conditions of the population, causing widespread toxic compounds contamination of soil, groundwater, open water, and atmosphere [2].

The analysis shows that modern schemes for effective management of domestic waste in most Russian cities do not receive proper implementation, mainly due to the lack of a systematic integrated approach and scientific justification for the selection and application of effective resource-saving technologies. On the other hand, according to the author, a serious problem in the waste management scheme is the differences underestimation in the urban development of large and small urban settlements specifics, in the nature of their territorial location and organization of transport links. In this article, the author justifies the importance of correct functional and urban planning strategy choosing for the solid domestic waste effective collection and processing in relation to the development and placement conditions of small regional settlements, that are geographically remote to large industrial centers.

2. Materials and Methods
The analysis shows that with the total number of large and small cities in Russia amounting to more than 1100 (with a population of 80 thousand people to 1.5 million people or more), only a small part of them have complexes for primary processing and disposal of solid waste. At the same time, there are only about 50 production complexes for the waste sorting in the country [3]. Even despite a number of organizational measures taken in some large cities, such as partial separate waste collection, pre-sorting and recycling of solid waste, the open air organized and unorganized landfill waste storage method prevails in the country as a whole [1:3]. Figure 1 shows a diagram that largely shows the current state of collection, transportation, and open air landfill storage of solid waste.

![Diagram](image)

**Figure 1.** The existing scheme of transport and planning organization of the collecting process, primary processing and export of solid domestic waste to remote landfill storage (adopted in the system of handling domestic waste in the territories of small, medium and large cities of the country).
Recently, the state authorities have taken important steps to implement a modern methodology for the municipal solid waste management in cities, providing for the phased creation of specialized enterprises in the primary infrastructure cities, aimed at involving waste in economic circulation as secondary material resources. This scheme involves the domestic waste separate collection, sorting and recycling (disposal) [4; 5]. Along with this, measures are envisaged to gradually reduce the unsorted waste export to landfill [6; 7]. In our opinion, the aforementioned scheme is most suitable for use in the large cities of Russia, since it provides for the organization of specialized industrial waste processing complexes in the territories of existing industrial zones of cities. According to the author, it is advisable to place such complexes in terms of rated capacity with reference to the territories of individual serviced public-residential areas of cities, which will significantly reduce undesirable mileage of specialized vehicles, reduce the load of city highways and the volume of toxic emissions [8].

At the same time, the town-planning analysis carried out by the author [2, 6, 8] shows that for the conditions of small cities and dispersed rural settlements in Russia, it will be necessary to develop a fundamentally different functional-planning model of waste management, which should be based on the principle of the separate territorial residential agglomerations formation as potentially sustainable sources of solid waste. Studies show that such residential agglomerations (in the form of specific groups of settlements) should provide conditions for the efficient collection, transportation and centralized processing of waste at specially created production enterprises. This enterprise module should be considered a functional core for each newly formed territorial planning entity.

In general, this concept provides for the formation of a new low-waste scheme as part of groups of small regional settlements on the territory of the country. The analysis also shows that one of the most important tasks in the implementation of the proposed concept is the choice of an effective functional scheme of the enterprise that provides the maximum waste-free character of solid waste processing and the principal possibility of complete elimination of landfill storage of solid waste[7, 8].

The domestic waste management methodology adopted in a number of countries of the European Economic Community (EU) is of interest, where a strategy for the active involvement of domestic waste in the economy in the form of secondary raw materials was adopted. This scheme provides for the introduction of a separate waste collection system in cities, which has also been included recently in the overall urban waste management strategy in Moscow and a number of large cities in Russia [9, 10, 11]. This scheme, in our opinion, is suitable at the initial stage of the general state strategy for waste management. According to experts, it is not perfect enough, causing high labor intensity and the cost of further recycling. At the same time, additional material, energy and transportation costs are required, as well as the previous problem of accumulation and removal of environmentally hazardous “tails” from waste recycling to existing landfills remains [3,6]. The analysis shows that this multi-stage scheme with partial utilization of domestic waste is the least acceptable for the geographically remote small towns and settlements in the regions of Russia distribution conditions.

In our opinion, a more promising is the modern methodology for domestic waste management, widely adopted in a number of countries of the European Economic Community (EU) with a developed diversified economy. It is based on a strategy for the domestic waste active involvement in the economy as a reliable and cost-effective renewable energy resource. This approach provides for the direct use of waste as a renewable energy source with heat and electricity industrial reproduction, replacing valuable non-renewable natural energy sources: coal, oil, natural gas. The strategy of domestic waste efficient management has been determined over the past years by a number of interstate acts (EU Directives), detailing the conditions for the waste collection and separation by type and chemical composition, environmentally acceptable storage conditions, as well as the use of effective industrial technologies to realize a valuable energy resource waste [12,13,14,15].
The analysis shows that to date, the thermal method of processing unsorted domestic waste with the generation of thermal and electric energy has received maximum distribution primarily in such European countries as Belgium, Germany, France, Sweden, Switzerland, as well as in Japan, the USA and China, where the share of thermal processing of waste from its initial mass is up to 50% or more. At the same time, a smaller part of the waste — up to 30% in these countries goes to industrial processing and disposal (recycling). With regard to waste sent to landfill, strong restrictions have also been identified on their acceptable sanitary and environmental qualities [16,17,18,19]. Taking into account the waste separate collection and deep pre-sorting in large and small cities of Europe, at the subsequent stage of SDW thermal processing at modern plants, a simple approved single-stage scheme for burning SDW and a two-stage scheme for subsequent treatment of waste flue gases is usually used. This scheme prevents the release of toxic substances into the atmosphere in the form of dioxins, furans and other harmful organochlorine compounds [15,20,21].

Over the past 20 years, similar technology incinerators, operating in the thermal power plants mode, have been built or reconstructed in Moscow. As the experience of their subsequent operation has shown, progressive European methods of single-stage incineration of unsorted solid waste have proved ineffective in terms of their sanitary and environmental qualities. The main reason for this was the extremely complex morphological and chemical initial composition of domestic waste in Russia, which is typical for most large and small cities in Russia. As has been proved by local experts, with a single-stage heat treatment scheme for unsorted multicomponent waste, chemically complex combustion products enter the subsequent gas treatment path with a lower technological temperature regime. This scheme in the conditions of domestic plants makes it possible to form secondary highly toxic chlorine and fluorine-containing components entering the surrounding atmosphere [21,22].

Taking into account the obvious expediency and efficiency of using a renewable valuable energy resource of domestic waste, native technologists, in relation to the characteristic composition of waste in Russian cities, proposed more effective improved schemes for heat treatment of solid waste and subsequent cleaning of combustion products [21,22]. These schemes are currently issued by a number of international patents and are recommended for widespread use in new construction and reconstruction of domestic waste incineration plants [23]. The fundamental solution for this method of solid waste processing is to organize a technological cycle with multi-stage high-temperature afterburning of exhaust flue gases, with their subsequent deep cleaning, which fundamentally ensures the complete destruction of highly toxic molecular compounds at the outlet of the chimney.

Thus, in relation to domestic practice, the plants for the municipal solid waste thermal processing in their qualities can become completely analogous to the traditional thermal power plants. The value of the new solid waste incineration scheme recommended by technologists is that it provides a highly environmentally friendly process for the thermal processing of large volumes of unsorted multicomponent high-humidity garbage, which is of exceptional importance for the location of such enterprises not only in large, but in the vast majority of medium and remote small cities of Russia [22]. At the same time, it becomes irrelevant to organize an expensive infrastructure of facilities for the preliminary solid waste sorting, transportation and additional processing of secondary products at specialized enterprises, with the processing “tailings” removal for landfill.

3. Results and Discussion

The author justifies in this article the correct functional and urban planning strategy choosing importance for the solid domestic waste effective collection and processing in relation to the development and placement conditions of small regional settlements that are geographically remote from large industrial centers. A scientific concept of such enterprises network organized planning placement for the small towns servicing conditions and remote rural settlements on the territory of
Russia is proposed and methodically worked out. The capacity of such an enterprise is methodically determined taking into account the specific composition of the surrounding settlements (individual residential agglomerations), the number of people living in them and the annual volume of incoming domestic waste. At the same time, taking into account the initial territorial dispersion of small cities, the most important factor is the provision of such local territories with road or rail transport communications. In particular, for the Central part of Russia conditions, it was proposed heavy use of the existing fairly developed Federal and regional Railways network. This solution can provide an effective way to collect and transport pre-compacted garbage from small urban settlements to the territory of a remote processing plant [24].

Thus, the idea of planning the formation of a regional residential agglomeration is realized, as part of a small urban settlements settlement group. United by a stable system of collecting objects, transporting and delivering solid waste for its waste-free thermal processing at the enterprise-module. The modular principle assumes technological repeatability of the small-sized enterprises location, used for the conditions of each formed residential agglomeration. This decision will allow excluding the development of hazardous landfills within a significant number of the Russian regions.

The proposed concept of the small residential agglomerations planning formation was tested in the course of design and experimental studies carried out at Moscow State University of Civil Engineering. The proposed settlement territorial agglomeration included such small regional cities as Elektrostal, Noginsk, Orekhovo-Zuevo, Yegoryevsk, with a population of 30-150 thousand people in each, as well as a number of adjacent rural settlements. An important factor in choosing this agglomeration was the provision of this territory with transit railways of local and regional significance, which will completely exclude the use of automobile garbage trucks for the delivery of waste to processing [24]. As the main facility for the solid waste processing, it was proposed that an environmentally friendly non-waste medium power thermal power plant operating on unsorted waste be proposed. The planned processing facilities system also provides for the special stations use for intermediate transshipment and container compaction of garbage placed in the cargo terminals of these small towns. Then the containers are delivered to the city railway station for shipment and subsequent thermal processing at the main enterprise. For the territories of adjacent rural settlements, in accordance with the concept under consideration, untreated domestic waste is transported by road to the nearest municipal garbage transfer station.

The fundamental condition of the recommended scheme is the determination of the optimal estimated amount of waste coming in as fuel and ensuring the stable operation of the thermal power plant. According to technologists [24], for the proposed conditions for regional location, it is advisable to use a small or medium annual capacity plant (not more than 120-150 thousand tons of SDW/year), which will ensure the stable operation of the enterprise and low critical emission loads. According to preliminary calculations, the enterprise provides energy recycling of waste for the above group of small towns and rural settlements with a population of up to 500 thousand people.

An important feature of the proposed thermal power plant solution of a new type is the use of a completely waste-free technological cycle. According to the calculations of technologists [22,25], the heat and electric energy generated by the enterprise is completely enough to cover its own needs and to provide energy to external regional consumers. In addition, it becomes possible to use deep thermal processing of ash and slag waste of the enterprise in special electric arc furnaces. The extremely strong granular slag obtained in this way from the melt with a volume of about 25 thousand tons/year is suitable for use as an environmentally friendly marketable product, primarily at local construction industry enterprises and in road construction [8,24,25].

The estimated boundaries of the selected area of the residential agglomeration in the developed pilot project cover an approximate territory with dimensions of 65x30 km. At the same time, in accordance
with the stated concept, the placement of the module enterprise in the conditions of the planning situation under consideration was provided for in the industrial zone of the existing railway junction, which ensures its environmentally safe removal from the groups of the settlements under consideration.

The result of the research is clearly illustrated in Figure 2, which shows the recommended layout of facilities based on the organization of a completely waste-free technological, transport and secondary product cycle using the parent enterprise module, which is planned to be located within the conditional boundaries of a single territorial agglomeration of small urban and rural settlements.

**Figure 2.** The proposed scheme for organizing an environmentally-friendly territorial production complex for the collection, transportation and thermal processing of solid waste as part of the formed territorial agglomeration uniting a group of small towns and rural settlements.

The estimated boundaries of the selected area of the residential agglomeration in the developed pilot project cover an approximate territory with dimensions of 65x30 km. Moreover, in accordance with the stated concept, the location of the module enterprise is provided for in the industrial zone of the existing railway junction, which ensures its environmentally safe removal from the groups of the settlements under consideration.

**4. Conclusions**

1. An analysis of urban solid waste management modern domestic practice in cities showed the problem of solid waste accumulation volume increasing severity at landfills, which causes serious environmental pollution in large areas of Russia. Moreover, the modern practice of organized collection, multi-stage industrial processing and waste disposal in Russia is, as a rule, in the initial
stage of development and is suitable for use in large cities. According to the analysis, a fundamentally different methodological approach to waste management and a new functional planning organization of solid waste processing facilities are required for the conditions for the location of geographically remote small towns and rural settlements.

2. The author proposed a new methodology for planning the organization of waste processing facilities for the conditions of small regional towns of Russia. It is based on the planning organization of small regional settlements in the form of separate territorial and residential agglomerations with the location of the main module enterprise, designed for a steady annual volume of incoming solid waste. An important condition for such an organization is the non-waste nature of the processing of solid waste, eliminating the environmentally hazardous landfill.

3. Based on the analysis of local and foreign experience, a promising type of the main production module for processing solid waste associated with the use of domestic waste as a reliable renewable source of energy resources is determined. As studies have shown, in this case, the developments of native technologists who recommend the improvement of the processes of afterburning of combustion products and the complete neutralization of emissions are of particular relevance. Thus, the enterprise operates in a thermal power plant with the possibility of direct use of unsorted waste as fuel, which is of exceptional importance for geographically remote small cities of Russia.

4. The results of the presented work were tested in the course of design and experimental studies on the example of the calculated formation of the territorial planning agglomeration as part of a specific group of small cities and adjacent rural settlements on the border of the Moscow region. The capacity of the environmentally low-waste enterprise for the thermal processing of solid waste, as well as the territorial boundaries of the agglomeration, were determined in accordance with the number of the population living within its borders. For the transport communications effective organization for containerized delivery of solid waste as part of the concept, the use of a regional railway network is proposed.

5. The results of the study allow us to identify new areas in the field of design methodology, based on the placement of technologically low-waste objects of garbage processing complexes, uniting functional-and-planning-wise the groups of previously territorially separated small cities of the Russian Federation. The relevance of research is determined by the possibility of their practical implementation at the next stages and provides for the implementation of priority comprehensive research with the participation of technologists, urban planners, economists and ecologists. Moreover, the enterprises themselves and their transport infrastructure may be a certain city-forming element that determines the sustainable development of territorial agglomerations of similar structure in many small Russian cities.

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