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Technogenic mineral accumulations: problems of transition to circular economy

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Abstract
The study hypothesis is determined by the statement that the identification of a set of issues covering all stages of introducing technogenic deposits into economic turnover will allow focusing on solving a set of complex problems associated with technogenic mineral accumulations (mining waste). The aim of the study was to identify problems requiring priority resolution, which, in turn, accelerated the transition to a circular economy (implementation of the concept of closed supply chains) in the context of handling technogenic mineral accumulations. In the course of the study, issues of legal nature were identified (caused by the absence of the legal status of technogenic deposits and the regulation of their use regime in the Federal Law of the Russian Federation "On Subsoil"). A number of aspects are due to the complexity and cost of development of technogenic deposits, which are rightfully classified as unconventional types of raw materials, and in most cases require state support (for involving in commercial exploitation) in the form of a system of economic incentives, the feasibility of which should be confirmed by newly-elaborated regulatory legal acts. State should use the tools of public-private partnership in solving waste problems, in particular, referring to the positively proven experience of implementing regional target programs for processing of technogenic mineral accumulations. Viability of transition to circular economy in the sphere of handling technogenic mineral accumulations depends on the timeliness of the identified problems solution.

Key words
technogenic deposits, technogenic mineral accumulations, waste, waste management, circular economy, public-private partnership

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ОПЫТ РЕАЛИЗАЦИИ ПРОЕКТОВ В ГОРНОПРОМЫШЛЕННОМ СЕКТОРЕ ЭКОНОМИКИ

Научная статья

Техногенные минеральные образования: проблемы перехода к циркулярной экономике

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Аннотация
Гипотеза исследования определяется утверждением, что выявление комплекса проблем, охватывающих все этапы введения техногенных месторождений в хозяйственный оборот, даст возможность сосредоточить внимание на вопросах, связанных с техногенными минеральными образования-

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ми (горнопромышленными отходами). Целью исследования является выявление задач, требующих первоочередного разрешения, что, в свою очередь, форсирует переход к циркулярной экономике (реализации концепции замкнутых цепей поставок) в условиях обращения с техногенными минеральными образованиями. В процессе исследования выявлены проблемы правового характера, обусловленные отсутствием в Федеральном законе Российской Федерации «О недрах» правового статуса техногенных месторождений и регламентации режима их использования. Ряд аспектов обусловлен сложностью и затратностью разработки техногенных месторождений, которые по праву отнесены к числу нетрадиционных видов сырья, и в большинстве случаев для использования требуют государственной поддержки в виде системы мер экономического стимулирования, возможность реализации которых должна быть подтверждена наличием проработанных нормативно-правовых актов. От государства требуется использование инструментов государственно-частного партнерства в решении проблем отходов, в частности, обращения к положительно зарекомендовавшему себя опыту реализации региональных целевых программ по переработке техногенных минеральных образований. Выявленные проблемы – далеко не последние, но от своевременности их решения зависит реальность перехода к циркулярной экономике в сфере обращения с техногенными минеральными образованиями.

Ключевые слова

техногенные месторождения; техногенные минеральные образования; отходы; обращение с отходами; циркулярная экономика, государственно-частное партнерство

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Introduction

The problem of waste for our country and the world community as a whole is not new. The waste amount increase is caused, on the one hand, by increasing mineral extraction amounts due to permanently increasing demand for raw materials and decreasing grades of ores of primary deposits, and, on the other hand, by low mineral raw materials utilization rate. According to research of V.I. Petryanov-Sokolov, carried out in the 1970s, only 2 % of natural materials are processed into finished products. Currently, this indicator has increased, but very slightly, and amounts to 2–6 %. According to the approximate calculations of the authors [1], the following amount of wastes is accounted for 1 ton of mineral, t: 1) coal: underground mining: 0.25–0.35, open-pit mining: 5–7; 2) iron ores: 1.0–1.5 (up to 10.0); 3) manganese ores: 2–3 and more; 4) industrial minerals: 0.2–0.4; 5) nonferrous metal ores: 1–5.0 (up to 20), etc.

Many useful components are lost in waste, and, in addition, the waste occupies more and more areas of land resources and become sources of pollution of the atmosphere, water resources, soil, and subsequently biota and humans. Mining production is defined as land-intensive: while extracting 1 million tons of manganese ore, from 76 to 600 hectares are disturbed; for iron ore, from 14 to 640 hectares; for 1m^3 of non-metallic raw materials, from 1.5 to 583 hectares; for 1 million tons of coal (underground mining), 4.4 hectares. The greatest alienation of lands from economic circulation and their transfer to industrial land category occurs in the course of open-pit mining, while in the structure of land use more than 75–80% of the total area are occupied by waste dumps and sludge storage facilities (TSFs). These facilities are especially dangerous in old industrial territories, including Sverdlovsk region, since, due to the growth of urban areas, in some cases the facilities prove to be within the city limits and become active sources of environmental degradation, affecting all elements of the biosphere. Mobile forms of heavy metals contained in them migrate in all directions, polluting water, soil, and plants. As a result, already at a distance of 9–10 km from the source of pollution, the ecological situation begins to deteriorate, which directly affects the population health [2–4].

Recently, the waste problem has become more sharp in connection with the completion of extracting reserves of deposits located in the central part of Russia with well-developed infrastructure, and the expediency of replenishing the mineral resource base at the expense of waste, the content of useful components in which often equals or even exceeds that in the ores of primary deposits [5]. At present, when the environmental aspect has been supplemented by the economic one, the problem of waste has become a priority, as evidenced by the targets of a number of legislative documents[1] and broad support for the concept of closed supply chains, or, according to the modern trend, the concept of a circular economy, which in their content are synonyms) [6–10].

The modern stage is characterized by the change from the so far dominating linear model following the principle: "extracting – consuming – discarding", to a fundamentally new model of circular economy, which is distinguished by: optimization of the production process, reuse or joint use of products, waste recycling. In March 2019, the European Commission approved the report on the circular economy action plan implementation, which reflected the existing achievements and formulated the tasks for the future [9]. The relevant documents, which reflected the circular economy integration, are European Green Deal [11] and COVID-2019 Recovery Plan [12]. These documents presents circular economy as an "urgent and irreversible global megatrend", contributing to the creation of a "sustainable, low-carbon, resource-efficient and competitive economy" [12, p. 1]. N.V. Pakhomova, K. Richter and M.A. Vetrova [6] argue that the main approaches to the formation of closed supply chains are: maintenance, product reuse, product refurbishment and/or component recovery. At the same time, both the concept of "circular economy" itself and the principles on which this concept is based, are still issues of scientific debate. The authors prefer the interpretation presented in the study [13], where the scientists argue that the "circular economy" should include a new working economic model, promote the transition from a linear model to a closed cycle of economic activity and be based on principles that include at least reuse, recycling and recovery of waste, and, ideally, a kind of classification (hierarchy) of waste, in which the principle of "reducing the use of natural resources and reducing adverse environmental impact" prevails.

The mining activity specifics make its own adjustments to the implementation of the circular economy model. In a narrower sense, this model can be implemented only for ore deposits, which account for 14.6% of the total extraction of minerals. In this case, the authors adhere to the opinion of K.N. Trubetskoy and Yu.P. Galchenko [14] on the impossibility of re-using nonmetallic raw materials, which forms the largest part of the flow coming from the lithosphere, as well as energy raw materials. For metal-containing waste, waste utilization methods such as recycling, recovery, and recuperation can be used. Recycling is the reuse of waste for its intended purpose; waste recovery involves the return of waste to the production cycle after a certain stage of preparation; recuperation provides for extraction of useful components. In the broad sense of the word, the circular economy model in essence corresponds to the resource saving model, which can be focused either only on mineral resources, or on all types of natural resources used in the development of subsoil resources (land, water, waste gases, etc.).

Despite the fact that the concept of circular economy is presented at this stage as an innovation, its origins can be traced back to the twentieth century. For instance, the problem of closed supply chains (circular economy) became an object of research in the 60s of the twentieth century. R. Parson calls for the collection of waste and their reuse (1969), calling this activity a "repeated cycle", which prevents depletion of mineral raw materials. He also considers it expedient to increase commercial reserves of mineral raw materials through the use of ores with low grade of useful components. Due to decreasing grades of useful components in iron ores, the transition to the extraction of ferruginous quartzite happened, and ash content in extracted coal increased. A striking example is the change in the copper grade in the mined ores in the United States (at the beginning of the twentieth century, the average copper grade in the ores was 5%, while by 1950 it dropped to 0.9%).

By the beginning of the 1980s, scientific research was intensified in the field of clarification of the conceptual and categorical apparatus of low-waste and non-waste-free technologies, generalization of the experience of their use in various industries, including mining, substantiation of the prospects for the development of waste-free production and waste disposal, consideration of this problem from the standpoint of rational use of feedstock, as well as the development of methodological approaches to assessing the economic efficiency of waste use. Among the researchers, T.V. Grant [15], V.A. Zaitsev, A.P. Tsygankov [16], B.N. Laskorin, B.V. Gromov [17], L.A. Barsky, V.Z. Persits [18], V.I. Chalov [19] should be mentioned. In 1983, L.A. Barsky and K.G. Gromov led the development of a Temporary Standard Methodology for assessing the economic

[1] FZ "On Amendments to the Federal Law" On Production and Consumption Waste" dated 29.12.2014 No. 458-FZ. (In Russ.). URL: http://www.consultant.ru/document/cons_doc_LAW_172948/; The strategy for the development of the industry for processing, utilization and disposal of production and consumption waste for the period up to 2030 dated January 25, 2018 No. 84r. (In Russ.). URL: http://static.government.ru/media/files/y8PMkQGZLfbY7jhn6QMruaKoferAowzJ.pdf; The strategy of environmental safety of the Russian Federation for the period up to 2025, approved by the Decree of the President of the Russian Federation of April 19, 2017 No. 176. (In Russ.). URL: http://www.consultant.ru/document/cons_doc_LAW_215668/

efficiency of low-waste technological schemes for processing mineral raw materials, while a number of similar industry methods had already been approved.

S.N. Podvishensky, V.I. Chalov, and O.P. Kravchenko considered, in their work [1], the issues of waste-free production from the perspective of the formation of mining complexes. A.D. Vyvarets examined waste in detail in order to increase the efficiency of their involvement in the production cycle [20]; V.N. Umanets and A.V. Kogut paid attention to exploration, quality assessment, geometrization and differentiation of waste by quality [21]. In the 80s, a team of scientists of Industrial Economics Institute (the Ukrainian SSR Academy of Sciences) quite actively and fruitfully dealt with the problem of rational use of waste, including their certification. The technogenic deposit classification issues, their role in information systems of mineral raw materials were studied in the researches of K.N. Trubetskoy, V.N. Umanets, M.B. Nikitin [22], as well as Yu.M. Arsky and V.V. Chainikov [23].

In the 1990s – early 2000s, the problem of waste was mainly considered within the framework of the concept of cleaner or environmentally friendly production (EFP), without being specified for the conditions of the mining sector. The issues of waste management in the regional aspect and related research on the development of mechanism for economic incentives for waste recycling were considered by M.N. Ignatyeva, G.Yu. Pakhalchak [24], I.S. Belik [25]; development of environmental entrepreneurship, by L.Ya. Yandyganov [26], development of the foundations for the theory and calculation of the parameters of such technologies, by K.N. Trubetskoy, A.G. Shapar [27], systematic assessment of technogenic mineral resources, by V.V. Chainikov [28]. The studies characterizing the mineral resource base represented by technogenic mineral accumulations were implemented by V.P. Konyaev, L.A. Kryuchkova, E.S. Tumanova [29], E.S. Tumanova, A.N. Tsibizov et al. [30], S.N. Mormil, V.L. Salnikova, L. Amosova et al. [31]. In the last decade, the following studies should be highlighted: Yu.A. Podturkin, V.A. Kotkin, R.Kh. Muslimov, R.N. Salieva [32], as well as V.B. Agafonov [33], which considered the legal support of economic activities in the field of the use of technogenic deposits; the study of S.M. Popov on the justification of waste uses [34]; L.Z. Bykovsky and L.V. Sporykhin, considering technogenic deposits from the perspective of expanding the mineral resource base [5]; S.G. Seleznev, touching upon the complexity of involving technogenic deposits in economic turnover [35]; B. I. Benevolsky, A.I. Krivtsova, A.I. Romanchuk, B.K. Mikhailova, considering the specifics of the economic and environmental aspects of mining and industrial waste utilization [36]; V.N. Umanets, who set out the methodology and experience of geological and technological assessment of technogenic gold formations at some deposits of Kazakhstan [37]; Yu.A. Kiperman and M.A. Komarov, which discussed the role of mining and industrial waste in the resource-saving development of the mineral resource complex [38]; as well as studies on the development of the circular economy concept of foreign authors [39–41] and its adaptation for Russian conditions - by domestic authors [6, 42]. The experience of implementing the concept using the “from bottom to top” method[2] [43] and “from top to bottom” [44] is subject to consideration.Moreover, there is a wide range of views and opinions in the world literature on the circular economy issues concerning the essence of the circular economy concept and basic principles [49], mechanisms of state regulation of the circular economy (the so-called "state regulation packages" [13] and their optimality [46, 47]); development and analysis of integration strategies for the circular economy [9, 48, 49] and some practical aspects of the circular economy application, including specific regulation mechanisms, issues of adjusting flows of resources and materials, "circular" technological innovations [50], and even techniques for teaching the very concept of circular economy [51], and so on.

Thus, the analysis of the studies carried out showed that they were characterized by the breadth of the subject matter, differences in the elaboration of individual issues and, at the same time, the lack of comprehensiveness in identifying problems impeding the implementation of resource-saving policy in mineral resource sector in the context of circular economy that predetermined the relevance and goal setting of the research performed. The purpose of this work was to identify problems requiring priority resolution for facilitating the transition to circular economy (implementation of the concept of closed supply chains) in the context of the treatment of technogenic mineral accumulations in the Russian Federation.

The initial condition for substantiating the subject of the research in the paper was an approach to the model of closed supply chains, i.e. the use of ore deposit exploitation wastes, or, more precisely, technogenic deposits (TD). As for the location of the studied targets, then from the environmental viewpoint, these were old industrial areas, where previously large-scale development of subsoil resources took place (for example, the Sverdlovsk and Chelyabinsk regions), as well as the northern and Arctic territories, whose fragile ecosystems were disturbed at the slightest

[2] Arctic industry and circular economy cluster. URL: https://arcticsmartness.eu/arctic-industry/

anthropogenic impact. Economically, these were TDs of strategic raw materials, as well as those that were located near metallurgical works and processing plants and could act as sources of raw materials that were in short supply for them.

Research Methodology

The hypothesis was determined by the statement that identifying a set of problems covering all stages of introducing TDs into economic circulation would make it possible to focus on eliminating bottlenecks and accelerate the implementation of resource-saving policies in relation to mineral resource sector based on MPW (mining-and-processing waste).

The methodological basis of the research included general scientific methods: historical, dialectical, abstract-logical, as well as methods of analysis, synthesis, comparison and analogies. Among the approaches used are system-based and evolutionary ones. The information base was composed of materials from the Ministry of Natural Resources and Ecology of Russia and its territorial divisions, the Federal State Statistics Service, regulatory legal acts and methodological documents, as well as the results of research by foreign and domestic scientists on the topic under consideration.

Findings and Discussion

Legal status of technogenic deposits

It should be noted that the concept of TD has long been recognized by the scientific community. According to the dictionary-reference book "this is an accumulation of mineral substances on the surface of the Earth or in mine workings, formed as a result of their separation from the rock mass and storing in the form of waste of mining, processing, metallurgical and other productions and suitable in terms of quantity and quality for commercial use as raw materials"[3]. The definition[4] clarifies the types of waste and indicates the need for processing with an economic effect. Surprising is the fact that the State Reserves Committee (GKZ) recognizes the presence of TDs, classifications of TDs are being developed [22], databases are created, while this concept is still absent in legislative documents, same to in the Federal Law "On Production and Consumption Waste", although it was already introduced in the Model Law "On Production and Consumption Wastes" of 2007[5]. At the same time, the concept of "TD" was enshrined in the first edition of the regional law "On Production and Consumption Waste" (Sverdlovsk region, 1997)[6], it is also present in the legislation on mineral resources of the Republic of Kazakhstan[7], and in the legislation of Uzbekistan[8]. This concept was introduced into the Law "On Subsoil" of the Republic of Tatarstan, into the "Instruction on the Application of the Mineral Reserves Classification to TDs Generated by the Coal Production in the Rostov Region".

Development of MPW deposits (i.e. TDs), on the one hand, in the Federal Law "On Subsoil"[9] is equalized with deposits of primary raw materials (organization of auctions and tenders for the transfer of the right to use them, conclusion of a service contract with a professional mining-rescue service etc.). On the other hand, in the Federal Law "On Production and Consumption Waste", MPW (mining-and-processing waste) is not separated into special units, but is considered simply as production waste, for processing of which it is necessary to have this waste in ownership. This condition simplifies the process of developing TDs, but does not comply with the provisions of the Federal Law "On Subsoil", where waste processing is one of the types of subsoil use, while the subsoil is in state ownership (Articles 1–2 of the Federal Law "On Subsoil"). Historical "ownerless" waste is also the property of the state.

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[3] Krivtsov A.I., Benevolskiy B.I., Minakov V.M., Morozov I.V. *Terms and concepts of domestic subsoil use: glossary*. Yatskevich B.A. (ed.). Moscow: CJSC Geoinformmark Publ.; 2000. (In Russ.).

[4] Methodological guideline for the study and environmental and economic assessment of technogenic deposits. GKZ under the Ministry of Environmental Protection and Natural Resources of the Russian Federation. Moscow: 1994. (In Russ.).

[5] The Model Law "On Production and Consumption Waste" (new version) adopted at the 29th plenary session of the Interparliamentary Assembly of the CIS Member States (Resolution No. 29-15 of October 31, 2007) (In Russ.). URL: https://docs.cntd.ru/document/902092609

[6] Law of the Sverdlovsk Region "On Production and Consumption Waste" dated December 19, 1997. Adopted by the Regional Duma of the Legislative Assembly of the Sverdlovsk Region on December 3, 1997. URL: https://docs.cntd.ru/document/801104148

[7] "On subsoil and subsoil use". Code of the Republic of Kazakhstan dated December 27, 2017 No. 125-VI 3PK. URL: https://adilet.zan.kz/rus/docs/K1700000125

[8] Law of the Republic of Uzbekistan dated September 23, 1994, 2018-XII "On Subsoil" (New edition, approved by the Law of the Republic of Uzbekistan dated December 13, 2002 No. 444-II). URL: https://buxgalter.uz/ru/doc?id=34547_zakon_respubliki_uzbekistan_ot_23_09_1994_g_2018-xii_o_nedrah_(novaya_redakciya_utverjdena_zakonom_ruz_ot_13_12_2004_g_nate)

[9] Law of the Russian Federation "On Subsoil" dated 02.21.1992 No. 2395-1. URL: http://www.consultant.ru/document/cons_doc_LAW_343/

As a result, at present time, the MPW management regulation is carried out in accordance with the Federal Law "On Subsoil", which implies huge payments, being sometimes commensurate with the profit from the TD development, to fulfill all the conditions related to geological exploration, approval of reserves, conclusion of contracts when a TD is recognized as hazardous industrial facility (HIF), etc. It follows from the above that there is an urgent need to determine the legal status of TDs in the Federal Law "On Subsoil" and the legal regime of their use. Until TDs are equalized in the legislation with natural deposits, the problem of their processing will remain unresolved, especially since, due to the peculiarities of the conditions of occurrence, composition and properties, development of TDs usually requires individual technologies/methods and equipment meeting the criteria of the best available technologies (BAT). This all significantly decreases potential profitability of corresponding TD investment projects, the implementation of which turns out to be unfeasible without state support. It is also required to specify in the Federal Law "On Production and Consumption Wastes" that the Law provisions do not apply to MPW, since MPW is regulated by the Federal Law "On Subsoil" in order to avoid misunderstandings and confusion.

Information support for handling technogenic deposits

Information about TDs, their location, source of accumulation, technogenic indicators (reserves, shape, grain size distribution, strength, etc.) is necessary to accelerate the involvement of waste in recycling. A correctly developed TD classification will become a basis for purposeful approach to the assessment and design of TD development, accelerated solving the problems of circular economy within the framework of mining sector. Analysis of the available classifications indicates that they reflect: the waste aggregative state (liquid, gaseous, solid); storage time (current, historical); danger level (toxicity, explosion hazard, infectivity and other properties). At the same time, all of them have a significant drawback connected with the lack of information on the economic feasibility of waste use, which was not avoided by the current regional cadastres of production and consumption waste, although back in 1987 in the sectoral methodology of cadastres for accounting for mining/processing/metallurgical waste (from non-ferrous metallurgy enterprises), the cadastres were named economic, since, in addition to the initial indicators characterizing waste, they contained a large list of economic indicators confirming the feasibility of TD processing. However, the methodology did not pay due attention to processing technology. Calculations of economic efficiency allow dividing TDs into three groups: 1) the use of which is expedient at the present time, 2) development is planned in the near future, and therefore the waste is subject to conservation, and 3) the use of which is impractical. The analysis of the current cadastres of production and consumption waste [52] showed that they contained information about the subject, the register of waste disposal facilities with more than 60 indicators presented in the form "Characteristics of waste disposal facilities", each of which was retrieval that allowed receiving information on various parameters. Data on legal entity – entrepreneurs carrying out activities for detoxication and disposal of waste, and data on techniques/installations for the use of waste are provided in the cadastres. This information concerns not only operating, but also decommissioned facilities; however, the cadastres do not contain data characterizing waste from the standpoint of the mineral resource base reserve.

Information about TDs is contained in the cadastre of mineral deposits and occurrences, while information in the cadastre of production and consumption waste for TDs doesn't allow separating TDs from other wastes used by nature users. There is no systematized information about TDs in the public domain, although attempts to study and evaluate them have been made more than once. For instance, at the end of the 80s of the XX century, PGO "Uralgeologiya" performed work on the preparation of geological and economic overview including assessment of potential use of waste from mining, metallurgical and fuel and energy industries. In 80–90s of the XX century, technological research and economic assessments related to mining waste disposal were carried out at such large enterprises of the Urals as Vysokogorsky GOK, Kachkanarsky GOK, NTMK OJSC, SUMZ OJSC, Svyatogor OJSC, BAZ, UAZ, etc. In 2002, a team of geologists under the leadership of S.I. Mormil summarized the data on accounting and processing of solid waste located within the Middle Urals, and also assessed their environmental hazard [31]. As the recuperation potential (that is, the possibility of additional extraction of useful components) of associated useful components in the technogenic mineral accumulations in the Sverdlovsk region, the following quantitative indicators for the facilities, shown in Fig. 1, can be considered.

Table 1 shows the specific facilities taken into account when drawing up the diagram, according to [31].

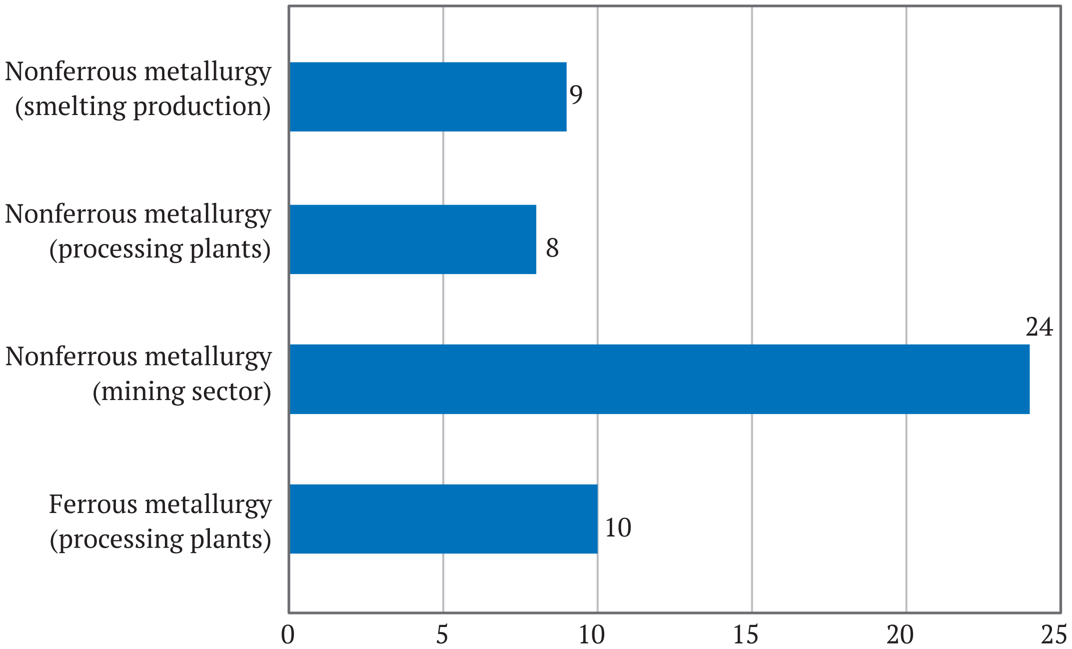

Fig. 1. Recovery potential of the Sverdlovsk region

Table 1

Technogenic mineral objects in the Sverdlovsk region, forming the recovery potential

Industry	Production	Enterprises	Waste type	Amount of waste, tons
Ferrous metallurgy (useful components: Fe, TiO_2, V_2O_2, Co, Sc, Cu, Zn)	Beneficiation production	OJSC Bogoslovsky RU	Crushing and screening plant (DSF) tailings	98.8
		OJSC Kachkanarsky GOK	Sludge from Magnetic Concentration Plant (MCP)	916,025.0
		OJSC Goroblagodatskoe RU	Sludge dump at Polovinka River	32,000.0
			Sludge dump at the Salda bog	47,552.0
		OJSC Vysokogorsky GOK	MCP beneficiation tailings, Cheremshanskoe sludge dump	36,718.0
			Zapadny open pit, MCP tailings	4,157.0
			Severo-Lebyazhinsky open pit, MCP tailings	2,300.4
			Kamensky open pit, MOF tailings	4,173.0
		OJSC Pervouralsky RU	Beneficiation tailings	14,148.0
			Sludge from sewage sump	540.0
		TOTAL (ferrous metallurgy, beneficiation production)		**1,057,712.2**
Non-ferrous metallurgy (useful components: Cu, Zn, Fe, S, Pb, Au, Ag)	Mining sector	OJSC Krasnoufimsk Copper Smelting Complex	Kabansky Mine, host rocks	3,732,000.0
			Chernushinsky Mine, host rocks	6,160,000.0
			Krasnogvardeisky Mine, host rocks	308,000.0
			Novolevinsky Mine, host rocks	187,600.0
		OJSC Volkovsky Mine	Off-balance ores	565,400.0
			Oxidized ores	3,168,300.0

End of Table 1

Industry	Production	Enterprises	Waste type	Amount of waste, tons
		III International SESchmidt Mine and Chadar Mine, host rocks	Shmidt and Chadar Mines, host rocks	173,900.0
			Severo-Olkhovskaya Mine, host rocks	112,600.0
			Yuzhno-Olkhovskaya Mine, host rocks	91,100.0
			Kapitalnaya Mine, host rocks	119,900.0
			15 years of October Mine, host rocks	243,900.0
			Sernaya Mine, host rocks	235,000.0
		OJSC Kirovograd Copper Smelting Complex (KCSK)	Levikhinsky Mine, host rocks (11 holes)	5,860,800.0
			Lomovsky Mine, host rocks	186,200.0
			Karpushinsky Mine, sludge from sewage and mine waters	22,300.0
			Belorechensky Mine, sludge from mine waters	166,400.0
			Levikhinsky Mine, sludge from mine waters	2,129,100.0
			Lomovsky Mine, sludge from mine waters	421,100.0
			Sulfuric acid plant of KCSC, sludge collector (mothballed)	167,100.0
			Sulfuric acid plant of KCSC, sludge collector (operating)	446,300.0
		OJSC Degtyarsky RU	Kapitalnaya Mine 1, 2, host rocks	4,464,000.0
			Elchevsky settling pond, sludge from mine waters	460,700.0
			Zyuzelsky settling pond, sludge from mine waters	44,000.0
		OJSC Safyanovskaya med’	Overburden	11,023,000.0
		TOTAL (nonferrous metallurgy, mining sector)		**40,488,700.0**
	Mining and Beneficiation Production	OJSC Krasnouralsk Copper Smelting Complex	Processing plant, historical beneficiation tailings (Sor’insky sludge pond)	8,742,000.0
			Current beneficiation tailings	6,734,400.0
		Kirovgrad processing plant	Historical beneficiation tailings	22,565,700.0
			Current beneficiation tailings	7,848,700.0
		Sredneuralsk processing plant	Historical pyrite beneficiation tailings	17,019,300.0
			Current beneficiation tailings	8,980,700.0
		OJSC Uralelectromed	Pyshma processing plant, historical beneficiation tailings	2,887,000.0
		OJSC Berezovsky Mine	Beneficiation tailings	16,941,800.0
		TOTAL (ferrous metallurgy, mining and beneficiation production)		**91,719,600.0**
	Metallurgical Production	OJSC Krasnouralsk Copper Smelting Complex	Reverberatory furnace slags, casting slags	513,500.0
			Historical granular slags	10,257,400.0
			Current granular slags	4,518,900.0

End of Table 1

Industry	Production	Enterprises	Waste type	Amount of waste, tons
		OJSC Kirovograd Copper Smelting Complex (KCSK)	Current shaft furnace slags (dumps 1, 2)	15,008,000.0
			Current shaft furnace slags	5,757,500.0
			Pyrite cinder, dump 1	785,500.0
			Pyrite cinder, dump 2	3,763,700.0
		OJSC Sredneuralsky Copper Smelter	Historical reverberatory furnace slags	12,654,400.0
			Current reverberatory furnace slags	8,301,000.0
		TOTAL (nonferrous metallurgy, mining and beneficiation production)		**61,559,900.0**

Thus, based on the data presented in Table 1 and Fig. 2, it should be noted that nonferrous metallurgy is in the lead in terms of the volume of waste generated (subject to recycling), in which processing (beneficiation) sector takes the first place, metallurgical production takes the second place, and mining sector takes the third place.

It was found that only a small portion of MPW has been studied geologically in order to identify, assess and approve their reserves, i.e. we can only talk about potential TDs.

The databank maintained since 2004 [52] contains information on 686 types of waste. A special problem is connected with ownerless "historical" waste, the value of which from the standpoint of forming mineral resource base reserve decreases due to long-term storage. They are considered most often as objects that pollute the environment, worsen the ecological situation, i.e. as objects of direct accumulation of environmental damage. According to the Order of the Russian Federation Government of 04.12.2014 No. 2462-r, 340 similar objects were identified in

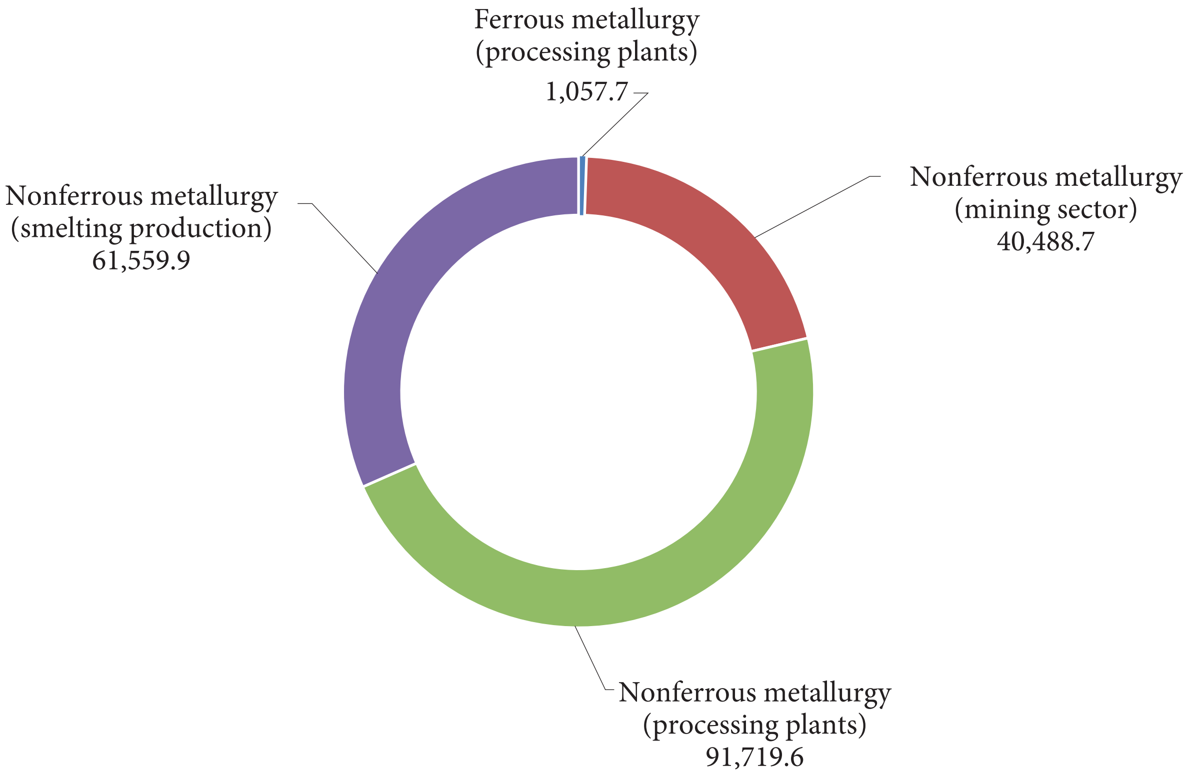

Fig. 2. Quantitative assessment of the volume of technogenic mineral accumulations in the Sverdlovsk region

Russia. The share of former TDs among which is unknown [53]. The number of ownerless objects in the territory of the Sverdlovsk region is 30, although most likely this figure requires clarification[10]. In the management of "historical" waste, the ecological aspect comes to the fore, since mineral raw material aspect in this situation almost loses its meaning. We believe that TD cadastre containing the most complete information about the objects, including economic information, allows obtaining reliable statistical information for making decisions regarding the use of TDs and intensifying this activity. It should not be forgotten that there is a large number of potential TDs in the country, reserves and resources of which have not been estimated, and there are numerous examples of this fact.

Licensing and assessment of TDs

According to the Federal Law "On Subsoil", it is necessary to obtain a license for the use of MPW, unless otherwise provided by a license for the extraction of the main mineral. Most often, a subsoil user, the owner of a license for the extraction of a mineral, is entitled to both exploration and processing of the resulting waste, BUT located within the boundaries of the mining lease allocated to the subsoil user. The need to obtain a separate license appears on the condition that the subsoil user either does not use current waste, or admits violations in the organization of this process noted during the inspection. If there is a historical waste within the boundaries of the mining lease, which falls into the licensing program, its processing requires obtaining a separate license, while the subsoil user exploiting this mining lease receives the preferential right to develop the TD. At the same time, the procedure for obtaining the right in accordance with the requirements of the Federal Law "On Subsoil" should be carried out through auctions (tenders), which is very problematic, especially for those that are included in the list of strategic raw materials, i.e. subsoil plots are of federal importance. The curiosity of the situation arises due to the fact that the decision on exploration and production of minerals in this case should be made only at the level of the Government of the Russian Federation. The list of licensed objects for TD development is usually formed by the Rosnedra territorial division; however, given the environmental hazard of a number of them, the list of the objects includes those that require immediate liquidation.

[10] Strategy for the industrial waste management in the territory of the Sverdlovsk region up to 2030, approved by Decree of the Government of the Sverdlovsk region of 09.09.2014, No. 774-PP. (In Russ.).

Obtaining the license is the first step in implementing waste recycling activities. The next step is a complicated and expensive procedure – geological assessment of MPW, which is assumed to be implemented similarly to natural deposits. The only regulatory document continues to be[11], recommending to carry out exploration using drilling of boreholes, sinking test pits, excavating trenches, which are subject to sampling. At the same time, exploration experience shows that reliability of sampling turns out to be low, since the large-block MPW material is sampled by small-size samples.

According to S.G. Seleznev, the sole reliable assessment criterion under these conditions is the results of pilot commercial development only, which is carried out by no means always [35]. He also notes the high cost of both geological exploration and the procedure of including the reserves on the state balance sheet (certification). The appraisal of TDs, which have already been included in the state balance sheet, was carried out in accordance with the requirements for comprehensive appraisal of reserves, first established in the "Temporary requirements for the calculation of associated minerals and components in ores and other types of mineral raw materials" in 1973. Later, the accumulated experience was reflected in the "Requirements for integrated study of deposits and estimation of reserves of associated minerals and components" (1982), which included a special section "Requirements for the study of waste from the main production" and a subsection "Requirements for the geological and economic appraisal of associated solid minerals".

According to the requirements, a deposit exploration provides for preliminary geological and economic appraisal of the overburden rocks and the implementation of detailed exploration with the reserve estimation. If these surveys were not executed during the exploration period, then according to the "Requirements for integrated study of deposits and estimation of reserves of associated minerals and components", the obligation to conduct these surveys falls on the deposit operator. The first appraisals of TDs as sources for obtaining mineral components were carried out in the 1930s in the Sverdlovsk Region. In 1931–1937, the dumps of the Turinsky mines were appraised for copper; in the same period, the copper-containing dumps of most enterprises in the Urals were also appraised. The appraisal work continued

[11] Methodological guideline for the study and environmental and economic assessment of technogenic deposits. GKZ under the Ministry of Environmental Protection and Natural Resources of the Russian Federation. Moscow, 1994. (In Russ.).

in 1956 and 1970s–1980s. Then their execution was terminated.

Unjustified indifference prevents the authorities from making changes to the legislative and regulatory framework regarding TDs being totally unlike natural deposits. TDs, according to scientists, at the initial stage of development can even be considered as unconventional raw materials, since "their development is innovative in nature and accompanied by increased costs and risks compared to traditional types of raw materials" [54]. This once again confirms the need for a differentiated approach to the use of TDs.

At the same time, the performed appraisal of TD for confirmation of reserves requires certain improvement based on modern realities. First, it concerns technologies that must comply with the best available technologies, introduction of which is determined by the Federal Law "On Amendments to the Federal Law" On Environmental Protection "and Certain Legislative Acts of the Russian Federation" dated July 21, 2014 No. 219-FZ. A list of BAT application areas, including mining sector, was approved by Order of the Government of the Russian Federation of 24.12.2014 No. 2674-r. Among them is the handling of overburden and host rocks. The second important point is the assessment of environmental hazard of waste, their impact on the environment. The recommendations of the regulatory document[12] are rather short; the provisions of the systematic approach to TD appraisal set forth in [28] are of better validity, although they do not take into account those changes in the calculation of prevented damage that are connected with socio-economic [55] and ecosystemic [56, 57] approaches to development of subsoil resources. When all the components are taken into account and assessed, the prevented damage turns out to be incomparably greater [58], than its estimated value using the methodology approved back in 1987. First of all, this concerns the underestimation of the value of biota ecosystem services, recovered after elimination of a technogenic source of environmental impact/damage. The dynamics of changes in the environmental impact in connection with changing state of waste with time due to transition of insoluble compounds and minerals into soluble forms owing to oxidation during filtration of atmospheric precipitation (containing free oxygen and acid solutions) through them also remains not taken into consideration.

From the above, it follows that it is necessary to study the technology of environmental transformation under the influence of mining industry. It is possible to use the ecological and geochemical principle, according to which the current "activity of technogenic loads determines material composition of water and air flows entering natural-territorial complexes (landscapes), depending on the content of sulfides and other active chemical elements and the aggregative state" [24]. All types of MPW in this case can be divided into geochemically hazardous and non-hazardous to the environment.

When appraising a TD, in contrast to natural objects, the environmental factor is of no less importance than the economic one that is reflected in the name of the appraisal performed: environmental-and-economic. This is primarily related to geochemically hazardous waste.

On the whole, it should be noted that a differentiated approach should be applied to the study, geological-and-economic appraisal, including in the state balance sheet and development of technogenic objects that differ in scale, mineral species types and ways of generation. Differentiated approaches should also be envisaged in relation to current and historical waste, large-block and sludge accumulations, mixed and differentiated waste storage, etc.

How the government can help

It follows from the foregoing that a TD development is a complicated and expensive business with high economic and environmental risks. In the current situation characterized by the lack of motivation to involve waste in the economic turnover, enterprises naturally choose more profitable strategy of actions, consisting in refusal to process waste, preferring to pay for negative environment impact caused by waste placement. At the same time, all researchers involved in the development of technogenic deposits confidently declare the need for state support in the form of a system of economic incentive measures for implementation of a program for processing of solid waste, all the more so as such mechanisms worked successfully in the 1980s. The economic mechanism in the field of waste management functioning in 2021, including the economic measures implemented in this area at the level of the regions of the Russian Federation, cannot be called sound.

The result of the review of domestic and foreign studies [59] on the problem of MPW processing for increasing the level of environmental safety, improving quality of the environment and preserving non-renewable resources was preparing a number of recommendations regarding the types of effective government assistance, which, in turn, will make it

[12] Methodological guideline for the study and environmental and economic assessment of technogenic deposits. GKZ under the Ministry of Environmental Protection and Natural Resources of the Russian Federation. Moscow; 1994. (In Russ.).

possible to intensify the process of MPW recycling by business.

1. "Implementation of state dedicated subsidy for development of environmentally friendly processing technologies, incl. BAT, waste detoxication and disposal, as well as interest subsidies to facilitate the use of borrowed funds.

2. Subsidized government lending and borrowing for equipment that ensures an environmentally friendly technological process for processing MWP; tax credits for introduction of new technologies (this practice is common in the USA) [60].

3. Preferential taxation (full or partial): exemption from taxation of commodity products produced and sold through extraction from MPW; exemption from taxation of a part of the profit of enterprises reinvested in MPW processing; exemption from income tax for newly created productions/startups aimed at MPW processing for two years since the initial receiving of profit; reducing MET rates (exemption for 1.5–2.0 years when introducing new technologies, full exemption when introducing environmentally friendly technologies) when using MPW as raw material; reduction of rates or complete exemption from property tax for enterprises extracting and processing MPW (technogenic resources) for newly created productions/startups; reduction of land tax rates; reduction of rental rates for the use of buildings and structures being in municipal and regional ownership.

4. Concessional lending of investment projects (taking into account their ranking) for MPW processing and forming a regional pledge fund, the guarantor of which is the regional government for reducing the investment risk of banking structures financing MPW processing. There is a positive experience of offset of costs for the implementation of measures for MPW rational use, development and implementation of low-waste and resource-saving technologies at the expense of payments for negative impact on the environment, as well as decreasing customs duties and excise taxes on equipment used in MPW processing, detoxication, and disposal, if such equipment is not manufactured in Russia. The positive aspects include those benefits that are provided for by No. 219-FZ for performing modernization, including activities related to MPW management. These are the possibility of reimbursement of the interest rate on the investment loan through corresponding reducing income tax; accelerated depreciation for the best available technologies (BAT) equipment (in the USA, for example, the writing off period for treatment equipment is 5 years, in Canada, 2 years), as well as return to the practice of forming environmental protection funds (ecological funds), the funds of which can be used to stimulate pollution prevention and maximum utilization of current MPW" [61].

At seemingly inattention to the institutions for supporting waste processing, nevertheless, a number of projects are supported by the government (processing of tungsten production waste into tungsten concentrate with giving preferential loan of 340 million rubles, solving the problem of waste processing within the cluster "Integrated processing of coal and industrial waste" on the basis of the Kuzbass Technopark, etc.

A promising tool for enhancing processing of solid waste is development of public-private partnership (PPP) in this area. For expanding PPP application, introducing legislative regulation of the procedure of interaction between the government and business (PPP agreement preparation, conclusion, execution, termination, etc.), as well as harmonization of various legislative acts, related to tax, land, environmental legislation, etc. A positive experience of interaction between the government and business in solving the problem of waste processing was noted in 1996 in the Sverdlovsk region. That year, the regional government formed and approved its own program of the constituent entity of the Russian Federation "Processing of MPW in the Sverdlovsk region" (in line with the Federal Program "Processing of MPW in the Sverdlovsk region"). Notice that the Federal Program was limited and consisted of 22 projects, whereas the regional one was open and permanently replenished with projects, the number of which reached 125 by the beginning of 2000 [62]. The program was implemented in two stages. The first stage (1997–1998) provided for implementation of 22 projects based on already developed technologies; at the second stage (1999–2005), the program involved development of new technologies and predominant processing of historical waste. The regional program implementation also implied the adjustment of the organizational mechanism for regulating MPW processing. To coordinate activities on the program implementation, a separate authorized body, Ural Institute of Metals LLC, was established.

In framework of the program, both new production facilities for processing of iron ore processing wastes were organized and existing ones were expanded at Vysokogorsky GOK, as well as slag-processing facilities at joint-stock companies Nizhny Tagil Metallurgical Complex, Klyuchevskoy Ferroalloy Plant, Seversky Pipe Plant, etc. were established or expanded (if existed). Finally, 20.1 million tons of waste from the mining and metallurgical sector were processed. On the whole, 35 kt of copper and copper concentrate, 2 kt of zinc, about 1 million tons of iron metal and magnetic product, 7 kt of ferrochrome, 7.5 million tons of building materials and 81.0 kt of asbestos were obtained [63]. For example, in 2010 alone, 13.6 million tons of MPW were processed, including 5289.3 kt of smelting waste, 6353.6 kt of mining and processing waste, and 48.5 kt of other waste related to the raw material sector. Unfortunately, in 2020, the program was terminated due to changes in federal budgetary and tax legislation resulting in termination of the government financial support. Nevertheless, the program implementation results proved to be very positive: new technologies were developed and introduced, the volume of waste recycling was almost doubled, and a number of enterprises received government support.

Conclusion

Long-term operation of mining enterprises in Russia resulted in accumulation of at least 80–100 billion tons of waste, which occupy considerable areas in the Central, Ural, West Siberian and other economic regions. Waste from mining and related processing industries is considered as a real reserve for expanding the country's mineral resource base [61, 64]. On the other hand, mining and processing wastes form a serious environmental problem for Russia due to the negative impact on both the environment and humans. The issues of waste processing and use of non-waste and low-waste technologies became urgent since the 60s of the XX century. In the 1990s, this issue was considered within the framework of the environmentally friendly production (EFP) concept, and later, within the framework of the concept of closed supply chains (circular economy). At present, when the environmental aspect has been supplemented by the economic one, the problem of waste has become a priority, as evidenced by the targets of a number of legislative documents and broad support for the concept of closed supply chains.

The transition from a linear economy model to a circular one requires overcoming a number of barriers in the context of ore deposits. First, a legal status of TDs and the legal regime of their use should be determined in the Federal Law "On Subsoil" that will prevent their legal equalization with natural deposits (taking into account their specific mode of occurrence, differing properties and, correspondingly, differing processing techniques) and simplify the procedure for their involvement in economic circulation. At the same time, TDs should not be regulated by the Federal Law "On Production and Consumption Wastes". The second point concerns information about TDs, which is currently either absent or very fragmentary.

Potential investors should have information for making decision concerning using TDs. The infor-mation completeness requires disclosing data on TD environmental hazard, possible processing techniques, and economic feasibility of TD development. The third problem to be solved is licensing and appraisal of TDs. We believe that when recognizing TD legal status, at the same time, changes should be incorporated into the procedure for their licensing, performance of appraisal work, including their reserves into the state balance sheet, given that, according to scientists, at the initial stages of development, they can be considered as non-traditional types of raw materials. When carrying out environmental and economic appraisal of TDs, a particular attention should be paid to the environmental aspect. Differentiated approaches are required with respect to current and historical waste, coarse-grained and sludge accumulations, mixed and differentiated waste storing.

The transition to circular economy model turns out to be impossible without government support. It is required to legislatively consolidate the mechanism of economic measures stimulating MPW processing, with timely development of the necessary regulatory documents. The PPP mechanism, which has proven its effectiveness in the conditions of the Sverdlovsk region, as well as regional target programs for MPW processing, should become promising tools for MPW processing.

Solving the identified problems will enable accelerating the transition to circular economy with regard to MPW management that will allow slowing down depletion of non-renewable natural resources, expanding waste processing, and reducing technogenic pressure on the environment.

References

1. Podvishensky S. N., Chalov V. I., Kravchenko O. P. *Rational use of natural resources in mining sector*. Moscow: Nedra Publ.; 1988. (In Russ.).

2. Rossman G. I., Pikalova V. S. The problem of ecological-economic evaluation of health damage in the preparation of feasibility study of conditions and development projects of mineral deposits. *Razvedka i ohrana nedr*. 2016;(11):52–58. URL: https://www.elibrary.ru/item.asp?id=24846526

3. Vormittag E., Saldiva P., Anastacio A., Barbosa F. Jr. High levels of metals/metalloids in blood and urine of residents living in the area affected by the dam failing in barra longa, district, brazil: A preliminary human

biomonitoring study. *Environmental Toxicology and Pharmacology*. 2021;83:103566. https://doi.org/10.1016/j.etap.2020.103566

4. Konte M., Vincent R. Mining and quality of public services: The role of local governance and decentralization. *World Development*. 2020;140:105350. https://doi.org/10.1016/j.worlddev.2020.105350

5. Bykhovsky L. Z., Sporykhina L. V. Industrial waste as a reserve to replenish mineral resources: status and development problems. *Mineral Recourses of Russia. Economics and Management.* 2011;(4):15–20. URL: https://elibrary.ru/item.asp?id=16716669

6. Pakhomova N. V., Richter K. K., Vetrova M. A. Transition to circular economy and closed-loop supply chains as driver of sustainable development. *St Petersburg University Journal of Economic Studies*. 2017;33(2):264–268. https://doi.org/10.21638/11701/spbu05.2017.203

7. Goyal S., Chauhan S., Mishra P. Circular economy research: A bibliometric analysis (2000–2019) and future research insights. *Journal of Cleaner Production*. 2021;287:125011. https://doi.org/10.1016/j.jclepro.2020.125011

8. Ignatyeva M., Yurak V., Pustokhina N. Recultivation of post-mining disturbed land: Review of content and comparative law and feasibility study. *Resources.* 2020;9(6):73. https://doi.org/10.3390/RESOURCES9060073

9. Smol M., Marcinek P., Duda J., Szołdrowska D. Importance of sustainable mineral resource management in implementing the circular economy (CE) model and the European green deal strategy. *Resources.* 2020;9(5):55. https://doi.org/10.3390/RESOURCES9050055

10. Sarja M., Onkila T., Mäkelä M. A systematic literature review of the transition to the circular economy in business organizations: Obstacles, catalysts and ambivalences. *Journal of Cleaner Production.* 2021;286:125492. https://doi.org/10.1016/j.jclepro.2020.125492

11. *European Commission. A European Green Deal.* 2020. URL: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

12. Calisto Friant M., Vermeulen W. J. V., Salomone R. Analysing European Union circular economy policies: Words versus actions. *Sustainable Production and Consumption*; 2021;27:337–353. https://doi.org/10.1016/j.spc.2020.11.001

13. Fitch-Roy O., Benson D., Monciardini D. All around the world: Assessing optimality in comparative circular economy policy packages. *Journal of Cleaner Production.* 2021;286:125493. https://doi.org/10.1016/j.jclepro.2020.125493

14. Trubetskoy K. N., Galchenko Yu. P. Mineral resource sector and natural biota of the earth. *Geoekologiya*. 2012;(6):483–489. (In Russ.).

15. Grant T. V. Prospects for the creation of waste-free productions in nickel industry. *Tsvetnye metally*. 1978;(12):7–15. (In Russ.).

16. Zaitsev V. A., Tsygankov A. P. The main trend of solving the problem of environmental protection is the creation of waste-free industrial production. *Zhurnal Vsesoyuznogo Khimicheskogo Obshchestva im. D.I. Mendeleeva*. 1979;(1):3–12. (In Russ.).

17. Laskorin B. N., Gromov B. V., Tsygankov A. P., Semin V. N. *The main problems of waste-free production development*. Moscow: Stroyizdat Publ.; 1981. (In Russ.).

18. Laskorin B. N., Barsky L. A., Persits V. Z. *Waste-free techniques for processing of mineral raw materials. Systematic analysis*. Moscow: Nedra Publ., 1984. (In Russ.).

19. Laskorin B. N., Chalov V. I. *Problems of waste-free production in metallurgical industry*. Moscow: TSNIIETsM Publ.; 1987. (In Russ.).

20. Vyvarets A. D. *Efficiency of waste use under the conditions of production intensification.* Sverdlovsk: USU Publ.; 1987. (In Russ.).

21. Umanets V. N., Kogut A. V. Evaluation of the quality and geometrization of mining and processing waste. *Razvedka i Ohrana Nedr*. 1987;(7):38–42. (In Russ.).

22. Trubetskoy K. N., Umanets V. N., Nikitin M. B. Classification of technogenic deposits: main categories and concepts. *Gornyi Zhurnal*. 1989;(12):6–9. (In Russ.).

23. Arskiy Yu. M., Chainikov V. V. The position of an economic cadastre in the mineral resources information system and its structure. Sun. articles: “*Industrial-and-economic cadastres of natural and technogenic deposits: theory and practice of development.*” Apatity, Academy of Sciences of the USSR; 1990, pp. 26–31. (In Russ.).

24. Ignatieva M. N., Pakhalchak G. Yu. The economic mechanism of resource-saving in the development of mineral resources potential. *Ural'skoe gornoe obozrenie*. 1996;(6):162–166 (In Russ.).

25. Belik I. S. A system of incentives for production waste use. Collection of essays: *Economic problems of nature management*. Sverdlovsk: UPI; 1991, pp. 11–12. (In Russ.).

26. Yandyganov Ya. Ya. *Environmental entrepreneurship in a region (problems, prospects, effectiveness)*. Yekaterinburg: UrEU Publ.; 1998. (In Russ.).

27. Trubetskoy K. N., Shapar A. G. *Low-waste and resource-saving techniques in open-pit mining*. Moscow: Nedra Publ.; 1993. (In Russ.).

28. Chainikov V. V. Systematic assessment of technogenic deposits. *Overview. Geology, methods of prospecting, exploration and estimation of mineral deposits*. CJSC Geoinformmark Publ. 1999;6–7. (In Russ.).

29. Konyaev V. P., Kryuchkova L. A., Tumanova E. S. *Technogenic mineral raw materials of Russia and its uses*. Moscow: JSC Rosnedra Publ.; 1994. (In Russ.).

30. Tumanova E. S., Tsibizov A. N. et al. *Technogenic resources of mineral construction raw materials*. Moscow: Nedra Publ.; 1991. (In Russ.).

31. Mormil S. I., Salnikov V. L., Amosov L. A. et al. *Technogenic deposits of the Urals and assessment of their environmental impact*. Yekaterinburg; 2002. (In Russ.).

32. Podturkin Yu., Kotkin V., Muslimov R., Saliyeva R. The problems of legal support of the anthropogenic deposits exploration. *Mine Surveying and Subsurface Use.* 2009;(6):29–33.

33. Agafonov V. B. Legal problems of managing waste from mining and associated processing plants. *Mineral Recourses of Russia. Economics and Management.* 2015;(2):60–64. URL: https://elibrary.ru/item.asp?id=23213698

34. Popov S. M. Methodological and procedural framework for the formation of directions for the use of production and consumption waste. *Mining Informational and Analytical Bulletin.* 2007;(5):81–86. (In Russ.). URL: https://giab-online.ru/files/Data/2007/6/11_Popov.pdf

35. Seleznyov S. G. On the problem of mining waste management. *Mineral Recourses of Russia. Economics and Management.* 2013;(4):40–44. URL: https://elibrary.ru/item.asp?id=20164735

36. Benevolsky B. I., Krivtsov A. I., Romanchuk A. I., Mikhailov B. K. Two aspects of the mining waste disposal problem. *Mineral Recourses of Russia.* 2011;(1):37–42. URL: https://elibrary.ru/item.asp?id=15591167

37. Umanets V. N. Experience in geological and processing assessment of man-made gold formations at some deposits in Kazakhstan. *Mineral Recourses of Russia. Economics and Management.* 2013;(4):87–93. URL: https://elibrary.ru/item.asp?id=20164742

38. Kiperman Y. A., Komarov M. A. Mining waste in the formation of resource saving environmental policy. *Mineral Recourses of Russia. Economics and Management.* 2016;(1–2):68–73. URL: https://elibrary.ru/item.asp?id=26136406

39. Mhatre P., Panchal R., Singh A., Bibyan S. A systematic literature review on the circular economy initiatives in the European union. *Sustainable Production and Consumption*. 2021;26:187–202. https://doi.org/10.1016/j.spc.2020.09.008

40. Ortega Alvarado I. A., Sutcliffe T. E., Berker T., Pettersen I. N. Emerging circular economies: Discourse coalitions in a norwegian case. *Sustainable Production and Consumption*. 2021;26:360–372. https://doi.org/10.1016/j.spc.2020.10.011

41. Harris S., Martin M., Diener D. Circularity for circularity's sake? scoping review of assessment methods for environmental performance in the circular economy. *Sustainable Production and Consumption.* 2021;26:172–186. https://doi.org/10.1016/j.spc.2020.09.018

42. Kharitonova G. N. Objective and preliminary prerequisites for the transition to "circular economy" in Arctic territories. *Strategies and tools for environmentally sustainable economic development: Proceedings of the XVth ROEE International Research-to-Practice Conference*. Stavropol-Kislovodsk; 2019, pp. 483–487. (In Russ.).

43. Tatarkin A. I., Polyanskaya I. G., Ignatyeva M. N., Yurak V. V. Consistent assessment of the status and prospects of institutional and innovational subsurface resources management in the arctic zone. *Economy of Region.* 2014;(3):146–158. https://doi.org/10.17059/2014-3-14

44. Su B., Heshmati A., Geng Y., Yu X. A review of the circular economy in China: Moving from rhetoric to implementation. *Journal of Cleaner Production*. 2013;42:215–227. https://doi.org/10.1016/j.jclepro.2012.11.020

45. Bovea M. D., Pérez-Belis V. Identifying design guidelines to meet the circular economy principles: A case study on electric and electronic equipment. *Journal of Environmental Management*. 2018;228:483–494. https://doi.org/10.1016/j.jenvman.2018.08.014

46. Givoni M., Macmillen J., Banister D., Feitelson E. From policy measures to policy packages. *Transport Reviews*. 2013;33:1–20. https://doi.org/10.1080/01441647.2012.744779

47. Bouma J. A., Verbraak M., Dietz F., Brouwer R. Policy Mix: Mess or Merit? *Journal of Environmental Economics and Policy*. 2019;8;32–47. https://doi.org/10.1080/21606544.2018.1494636

48. Vanhamäki S., Virtanen M., Luste S., Manskinen K. Transition towards a circular economy at a regional level: A case study on closing biological loops. *Resources, Conservation and Recycling*. 2020;156:104716. https://doi.org/10.1016/j.resconrec.2020.104716

49. Vanhamäki S., Rinkinen S., Manskinen K. Adapting a Circular economy in regional strategies of the European Union. *Sustainability*. 2021;13(3):1518. https://doi.org/10.3390/su13031518

50. Winans K., Kendall A., Deng H. The history and current applications of the circular economy concept. *Renewable and Sustainable Energy Reviews*. 2017;68(1):825–833. https://doi.org/10.1016/j.rser.2016.09.123

51. Nunes B. T., Pollard S. J., Burgess P. J., Ellis G., De los Rios I. C., Charnley F. University contributions to the circular economy: Professing the hidden curriculum. *Sustainability*. 2018;10(8):2719. https://doi.org/10.3390/su10082719

52. Orlova O. N., Bobina N. A. On the establishment and maintenance of the Sverdlovsk regional production and consumption waste cadaster. *Mineral Recourses of Russia. Economics and Management*. 2013;(4):45–47. URL: https://elibrary.ru/item.asp?id=20164736

53. Solovyanov A. A. Historical (accumulated) environmental damage: Problems and solutions. 7. Implementation of the order of the Government of the Russian Federation of 04.12.2014 No. 2462-r. *Ekologicheskij vestnik Rossii*. 2015;(9):42–48. (In Russ.). URL: https://elibrary.ru/item.asp?id=24187966

54. Larichkin F. D., Kamenev E. A., Motlokhov V. V. Non-traditional types of mineral raw materials: relevance, definition and classification. *Gornyi Zhurnal*. 2003;(1):16–20. (In Russ.).

55. Ignatyeva M. N. The main provisions of the geo-eco-socio-economic approach to the development of natural resources. *News of the Ural State Mining University*. 2014;(3):74–80. (In Russ.).

56. Perelet R. A. Ecosystem approach to environmental management and protection. *Ekonomika prirodopol'zovania*. 2006;(3):3–19. (In Russ.).

57. Yurak V., Emelyanova E., Kostromina T. Ecosystems' economic assessment in the context of different climatic zones. In: *E3S Web of Conferences*. XVIII Scientific Forum "Ural Mining Decade" (UMD 2020). 2020;177:04013. https://doi.org/10.1051/e3sconf/202017704013

58. Loginov V. G., Ignatyeva M. N., Balashenko V. V. Harm to the resources of Traditional nature management and its economic evaluation. *Economy of Region*. 2017;13(2):396–409. https://doi.org/10.17059/2017-2-6

59. All-Russian conference "Problems of rational use of mining waste". April 25–26, 2013. *Mineral Recourses of Russia. Economics and Management*. 2013;(4):95–98. URL: https://elibrary.ru/item.asp?id=20164743

60. Hassett K. A., Metcalf G. E. Energy tax credits and residential conservation investment: Evidence from panel data. *Journal of Public Economics*. 1995;57(2):201–217. https://doi.org/10.1016/0047-2727(94)01452-T

61. Kubarev M. S., Ignatyeva M. N. Economic incentives for processing of technogenic mineral accumulations. *Samarskaa Luka: problemy regional'noj i global'noj ekologii*. 2018;27(3):143–147. URL: http://www.ssc.smr.ru/media/journals/samluka/2018/27_3_17.pdf

62. Danilov N. I. The program for processing of technogenic accumulations in the Sverdlovsk region. Primary areas and implementation results *Proceedings of Higher Educational Institutions. Gornyi Zhurnal. Ural'skoe Gornoe Obozrenie*. 1997;11–12:4–7. (In Russ.).

63. Danilov N. I., Smirnov L. A., Leshchikov V. I. Experience of utilization of technogenic accumulations in the Sverdlovsk region. *Mineral Recourses of Russia. Economics and Management*. 2000;(5–6):41–51. (In Russ.).

64. Polyskaya I. G., Yarak V. V., Strovsky V. E. Considering mining wastes as a factor of increasing the balance level of subsoil management in regions. *Economy of Region*. 2019;15(4):1226–1240. https://doi.org/10.17059/2019-4-20

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