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CONTENTS

WAYS TO EXPAND THE COMPANY'S POSITION IN THE FURNITURE MARKET 6
Musayeva Shoira Azimovna

DIRECTIONS FOR IMPROVING THE ORGANIZATIONAL AND ECONOMIC MECHANISM OF MEDICINAL PLANT PROCESSING 11
Usmonov Mirgulom Khoshim ogli

POLITICAL RELATIONS BETWEEN AZERBAIJAN AND UZBEKISTAN: HISTORY, CHALLENGES, AND PROSPECTS 17
Naila Ramazanova

ANALYZING THE SUSTAINABILITY OF REGIONAL ECONOMIES USING MULTI-CRITERIA INDICES AND MODEL OPTIMIZATION 23
Sattorov Sanjar Abdumurodovich

ECONOMIC ADVANTAGES OF MODERNIZING THE EDUCATION SYSTEM THROUGH INNOVATIVE TECHNOLOGIES 28
Rakhmatkhodjayev Akhrorkhodja Akmal ugli

XORIJIY MAMLAKATLAR KORPORATIV BOSHQARUV VA INNOVATSION RIVOJLANISH MODELLARINING QIYOSIY TAHLILI 34
Ismailov Allayor Rashidovich

DIGITALIZATION OF FOREIGN EXCHANGE DIFFERENCE ACCOUNTING: CHALLENGES AND PROSPECTS IN EMERGING ECONOMIES 41
Pulatov Sirojbek, Misirov Kamoldin

ВЛИЯНИЕ СОЦИАЛЬНО-ДЕМОГРАФИЧЕСКИХ ФАКТОРОВ НА ОБЕСПЕЧЕНИЕ ЭКОНОМИЧЕСКОЙ БЕЗОПАСНОСТИ СТРАНЫ 47
Ташмухамедова Яйра Атхамовна

MAIN MEASURES TO STRENGTHEN EMPLOYMENT STABILITY AND IMPROVE EMPLOYMENT MANAGEMENT IN UZBEKISTAN 52
Abdullayeva Nigora Shamsiddinovna

ECONOMETRIC ANALYSIS OF THE IMPACT OF INVESTMENTS ON THE CREATION OF NEW JOBS 57
Shayzak R. Kholmuminov, Shukhrat Sh. Kholmuminov

RAQAMLASHTIRISH VA YASHIL TURIZM KONSEPSIYASI ASOSIDA TURIZM SOHASINING BARQAROR RIVOJLANISHI 68
Xaitov Oxunjon Nomoz o'g'li

IQTISODIYOTDA DAVLAT ISHTIROKINI QISQARTIRISH ORQALI XUSUSIY SEKTOR ROLINI OSHIRISHNING IJTIMOIY MUHITGA TA'SIRI 73
Musurmonqulov Muhammad

DIAGNOSIS OF EMOTIONAL INTELLIGENCE DEVELOPMENT IN PRESCHOOL CHILDREN: METHODS AND RESULTS 77
Abduxamidova Dilorom Abdumuminovna

MULTIMADANIY MUHITDA PEDAGOGLARNING TANQIDIY FIKRLASH KO'NIKMALARINI SHAKLLANTIRISH MEXANIZMLARI 81
Gulyamova Nafisa Burikulovna

WAYS TO IMPROVE MARKETING SERVICES IN A FURNITURE MANUFACTURING ENTERPRISE 85
Mukhtarov Samadjon Abdusattor ugli

THE ROLE OF SMALL AND MEDIUM-SIZED ENTERPRISES (SMES) IN ENHANCING UZBEKISTAN'S EXPORT PERFORMANCE 90
Abduvoitov Bekzod Khikmatullaevich, Dr. Navik Istikomah, S.E., M.Si

OPPORTUNITIES FOR FURTHER DEVELOPMENT OF THE TOURISM SECTOR WITH THE HELP OF AN INNOVATIVE IT PLATFORM 99
Nasrullaev Hikmatullo Habibulloevich

CONTENTS

DIGITALIZATION OF AGRICULTURAL PRODUCTS FOR EXPORT 105
Azimov R.B.

IQTISODIYOTDA TO‘G‘RIDAN-TO‘G‘RI XORIJIY INVESTITSIYALARNI ROLINI OSHIRISH 109
Ruzibayeva Nargiza Xakimovna, Ro‘ziqulov Abduqahhor Ixtiyor o‘g‘li

SUSTAINABLE DIGITAL TRANSFORMATION STRATEGIES FOR INTERNATIONAL TRADE 114
Kurolov Maksud Obitovich

THE DEVELOPMENT OF THE METAL MARKET AND THE ROLE OF SMALL BUSINESSES IN IT 129
Musinov Dilshod Sultanovich

ANALYSIS OF EXISTING TECHNOLOGICAL SOLUTIONS TO THE PROBLEM OF WATERING GAS WELLS 134
Abdirazakov Akmal Ibrahimovich, Boymurodov Boynazar Muradillayevich

РЕФОРМЫ РЕЛИГИОЗНО-ОБРАЗОВАТЕЛЬНОЙ СФЕРЫ УЗБЕКИСТАНА 140
Тиллябаева Гульсунхон Бахрамовна

MODELS FOR ENHANCING THE COMPETITIVENESS OF SMALL BUSINESS ENTERPRISES 144
Melibayeva Gulxon Nazrullayevna

TEXTILES AND SEWING-KNITTING INDUSTRY DEVELOPMENT STATUS AND PRODUCTION VOLUME FORECAST 152
Ikromova Takhmina Latifovna

BIG DATA VA PREDICTIVE ANALYTICS YORDAMIDA KORXONA MOLIYAVIY RISKLARNI BASHORAT QILISH VA BOSHQARISH 159
Karimov Xondamir Jamshid o‘g‘li

WAYS TO IMPROVE ALTERNATIVE FINANCING OF INVESTMENT ACTIVITIES 166
Boboqulov Akmal Muborakbekovich

VENTURE CAPITAL IN UZBEKISTAN: ECOSYSTEM ASSESSMENT, KEY CHALLENGES, POLICY IMPLICATIONS 173
Umidjon Khoshimov

STUDY OF ELECTRONIC WASTE RECYCLING IN UZBEKISTAN BASED ON THE EXPERIENCE OF UZVTORTSVETMET AND THE ALMALYK MINING AND METALLURGICAL COMPLEX 183
Musayev Marufjan Nabievich, Ergashev Sardor Bakhtiyor ogli

STUDY OF ELECTRONIC WASTE RECYCLING IN UZBEKISTAN BASED ON THE EXPERIENCE OF UZVTORTSVETMET AND THE ALMALYK MINING AND METALLURGICAL COMPLEX

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Abstract: The article presents a study of the electronic waste recycling system in Uzbekistan using the example of two enterprises: JSC “Uzvtorsvetmet” and the Almalyk Mining and Metallurgical Complex. The features of manual disassembly and sorting of waste at Uzvtorsvetmet, as well as the industrial extraction of precious metals at the Gold and Silver Refinery Shop of the Almalyk MMC, are examined. Data on the technologies used and the volumes of metals obtained in 2025 are provided. Key problems are noted — a low level of mechanization, a limited system of waste collection from the population, and low economic efficiency. The necessity of introducing modern technologies and developing infrastructure to form a sustainable national electronic waste management system is emphasized.

Key words: electronic waste, recycling, study, Uzbekistan, Uzvtorsvetmet, Almalyk Mining and Metallurgical Complex, precious metals, pyrometallurgical method, electrolysis, environmental sustainability.

Annotatsiya: Maqolada O‘zbekistonda elektron chiqindilarni qayta ishlash tizimi ikki korxona misolida o‘rganilgan: “O‘zikkilamchiranglimetall” AJ va Olmaliq kon-metallurgiya kombinati. “O‘zikkilamchiranglimetall”da chiqindilarni qo‘lda ajratish va saralash xususiyatlari, shuningdek, OKMKning Oltin va kumush affinaj sexida qimmatbaho metallarni sanoat miqyosida ajratib olish jarayonlari ko‘rib chiqilgan. 2025-yilda qo‘llanilgan texnologiyalar va olingan metall hajmlari haqida ma’lumotlar keltirilgan. Asosiy muammolar sifatida past darajadagi mexanizatsiya, aholining chiqindilarni topshirish tizimining cheklanganligi va iqtisodiy samaradorlikning pastligi qayd etilgan. Zamonaviy texnologiyalarni joriy etish hamda barqaror milliy elektron chiqindilarni boshqarish tizimini shakllantirish uchun infratuzilmani rivojlantirish zarurligi ta’kidlangan.

Kalit so‘zlar: elektron chiqindilar, qayta ishlash, tadqiqot, O‘zbekiston, O‘zikkilamchiranglimetall, Olmaliq kon-metallurgiya kombinati, qimmatbaho metallar, pirometallurgik usul, elektroliz, ekologik barqarorlik.

Аннотация: В статье представлено изучение системы переработки электронных отходов в Узбекистане на примере двух предприятий — АО «Узвторцветмет» и Алмалыкского горно-металлургического комбината. Рассмотрены особенности ручной разборки и сортировки отходов на «Узвторцветмет», а также промышленного извлечения драгоценных металлов в Цехе аффинажа золота и серебра Алмалыкского ГМК. Приведены данные о применяемых технологиях и объёмах полученных металлов в 2025 году. Отмечены ключевые проблемы: низкий уровень механизации, ограниченность системы сбора отходов от населения и малая экономическая отдача. Подчёркнута необходимость внедрения современных технологий и развития инфраструктуры для формирования устойчивой национальной системы управления электронными отходами.

Ключевые слова: электронные отходы, переработка, изучение, Узбекистан, Узвторцветмет, Алмалыкский горно-металлургический комбинат, драгоценные металлы, пирометаллургический метод, электролиз, экологическая устойчивость.

INTRODUCTION

Electronic waste represents one of the fastest-growing waste streams in the world and, at the same time, a source of serious environmental and economic problems. It contains toxic elements such as lead, mercury, and cadmium, as well as valuable resources like gold, silver, copper, and rare-earth metals.[1] On one hand, improper handling of electronic waste poses threats to public health and the environment. On the other hand, with proper recycling, it can become an additional source of precious and non-ferrous metals that are in demand across various sectors of the economy.[2]

In Uzbekistan, the issue of electronic waste recycling is gaining increasing importance.[3] As digitalization expands and the market for electrical and electronic products grows, the annual volume of waste continues to rise. For instance, the production volume of electrical and electronic equipment in the country increased from 17.4 trillion soums in 2021 to 22.4 trillion soums in 2023, indicating the growth of future waste volumes (Figure 1).[4] At the same time, the infrastructure for waste collection and recycling remains limited. In 1996, by a resolution of the Cabinet of Ministers of the Republic of Uzbekistan, responsibility for the safe disposal of electronic waste was assigned to the Almalyk Mining and Metallurgical Plant. This decision defined the enterprise's key role in establishing a national system for electronic waste recycling (Figure 1). [5]

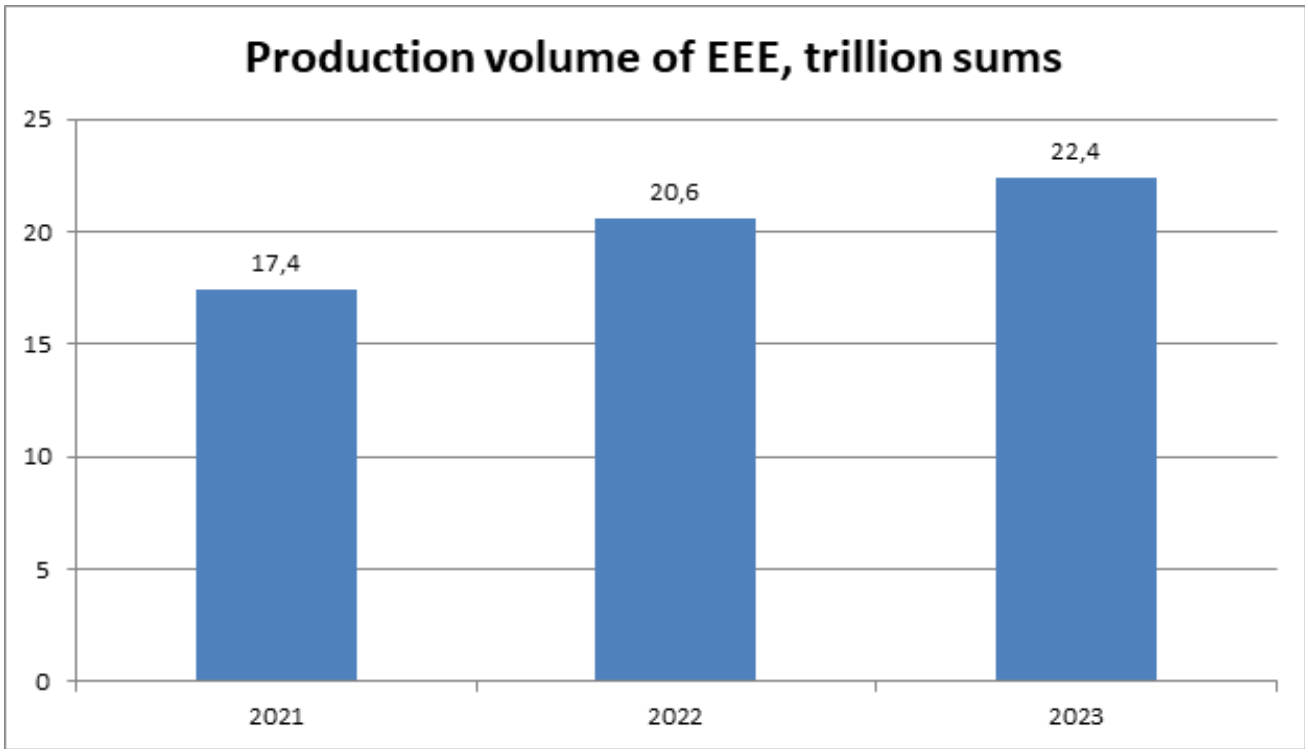

Figure 1. Production volume of electrical and electronic equipment in Uzbekistan (trillion soums)

REVIEW OF LITERATURE ON THE SUBJECT

The global academic literature on electronic waste recycling provides a solid foundation for analyzing Uzbekistan's experience through Uzvtorcvetmet and the Almalyk Mining and Metallurgical Complex. Fortunat Baldé and his team at the United Nations University, in their Global E-waste Monitor, identify Central Asia—including Uzbekistan—as a region with low formal recycling rates and a strong dependence on metal-scrap channels for secondary raw materials. They argue that effective e-waste policy must link existing metallurgical industries with new collection and processing networks.

At the national level, Aidos Sadinov examines Uzbekistan's recycling sector in his study Improving Waste Recycling in Uzbekistan through Digital Technologies, emphasizing the role of automated control systems and digital tracking in formalizing collection networks. His research shows that digital integration could significantly raise recovery efficiency in enterprises such as Uzvtorcvetmet.

The National E-waste Monitor – Uzbekistan prepared by Fortunat Baldé, Vanessa Forti, and Ruediger Kuehr provides the first systematic assessment of e-waste generation and management in the country. Their analysis highlights the minimal recovery of valuable metals and the need for a circular-economy strategy linking collection points with metallurgical facilities like Almalyk MMC.

In the industrial context, Uzvtorcvetmet's own technical documentation demonstrates its capacity for non-ferrous scrap collection and sorting, while Almalyk Mining and Metallurgical Complex reports on refining technologies capable of recovering copper, gold, and silver from complex raw materials. Ravshan Rakhimov in his article Metallurgical Recycling Potential of Industrial Waste in Uzbekistan notes that integrating electronic scrap into Almalyk's refining circuit could substitute part of imported concentrates, provided environmental and occupational standards are observed.

On the socio-economic side, Zulaykho Abdurakhmanova and Bakhtiyor Saidov from Tashkent State University of Economics analyze green-economy transitions and show that formal e-waste recycling could generate employment and new value chains while reducing environmental risks. Their findings complement Baldé's global framework by demonstrating how national industrial policy can anchor circular-economy initiatives in existing metallurgical enterprises.

Overall, these studies collectively confirm that Uzbekistan's e-waste management system is still at an early stage but benefits from having strong industrial actors such as Uzvtorcvetmet and Almalyk MMC, whose modernization could form the backbone of a national recycling infrastructure aligned with international best practices.

RESEARCH METHODOLOGY

The research methodology is based on the collection of statistical data from Uzvtorcvetmet and the Almalyk Mining and Metallurgical Complex, as well as official reports from the World Bank and the National E-waste Monitor. The obtained data were analyzed using comparative and descriptive methods to evaluate recycling efficiency, material recovery rates, and the economic potential of electronic waste management in Uzbekistan.

ANALYSIS AND RESULTS

Practice shows that today the recycling of electronic waste involves both specialized enterprises engaged in preliminary sorting and dismantling, and large metallurgical plants where the extraction of precious metals is carried out.[6] Studying the operations of JSC Uztortsmet and the Almalyk Mining and Metallurgical Complex makes it possible to clearly illustrate the existing model of electronic waste recycling in Uzbekistan, identify its strengths and weaknesses, and outline prospects for further development.

Additional attention to this topic is also driven by international trends in sustainable development. In a number of countries, electronic waste recycling is considered a strategic area that simultaneously reduces environmental damage and provides the economy with secondary resources.[6] For Uzbekistan, studying and adapting such practices, combined with the development of national infrastructure, forms the foundation for building an efficient electronic waste management system.

An examination of the processes at JSC Uztortsmet revealed that this enterprise plays a key role in the initial stage of electronic waste management in Uzbekistan. The plant receives batches of decommissioned equipment from government agencies, universities, and other large organizations. These wastes first undergo manual disassembly and sorting, carried out in a specially designated office equipment department. Workers use basic tools — screwdrivers, hammers, and pliers — to dismantle computer system units, monitors, telephones, and office equipment. At this stage, plastic parts, metal casings, and electronic boards are separated and then sent to specialized recycling units. A visual representation of these processes and accumulated waste is shown in the plant photographs.

Particular attention is paid to the careful handling of components containing potentially hazardous elements. For example, fluorescent lamps and monitor parts are not subjected to mechanical destruction to prevent the release of toxic substances. They are stored separately and prepared for specialized recycling processes. This approach reflects growing environmental responsibility and creates a foundation for further technological development aimed at implementing safe neutralization systems directly at the enterprise.

The study revealed that recycling operations at Uztortsmet are still primarily based on manual labor. However, this also indicates significant potential for modernization and mechanization. The introduction of automated sorting lines, hydrometallurgical and combined methods will allow a more efficient recovery of valuable materials such as gold, silver, and copper. In this context, the enterprise can gradually transform from a sorting facility into a full-fledged resource recovery center, ensuring higher environmental and economic efficiency (Figure 2).

Figure 2. UZVTORTSVETMET Plant — Office Equipment Department.

An equally important direction for development is the creation of a comprehensive system for collecting electronic waste throughout the country. At present, the main batches are supplied by large organizations, which forms a solid initial base for scaling collection efforts. Although collection from the general population is still limited, this situation opens up opportunities for designing and implementing effective incentive mechanisms. Occasional social media initiatives that announce the acceptance of old or unused equipment show that public awareness is gradually increasing. These activities, if supported institutionally, can become the foundation for the establishment of a stable, large-scale, and systematic collection practice in the near future. As these programs expand, a significant proportion of household-generated electronic waste will be redirected from traditional solid-waste landfills into formal recycling channels, contributing to environmental protection and resource efficiency.

The analysis of Uztortsmet's activities demonstrates that the enterprise plays an essential role as the primary link in the electronic waste recycling system. Its operations provide a critical foundation for subsequent stages of processing. While the enterprise currently relies heavily on manual labor and maintains a relatively low level of mechanization, this also indicates a significant modernization potential. The gradual introduction of automated sorting technologies, mechanical separation systems, and environmentally friendly processing methods will enable the company to improve its recycling efficiency and recover larger volumes of valuable materials such as gold, silver, and copper. Thus, Uztortsmet has all the prerequisites to transform from a preparatory sorting facility into a modern, full-fledged center for resource recovery. In addition, its established practices of careful waste sorting and strict adherence to environmental safety standards represent a solid methodological basis for future technological progress.

The study of the Almalyk Mining and Metallurgical Complex (AMMC) confirms that the enterprise performs a nationally significant function in the field of electronic waste disposal, as defined by the 1996 resolution of the Cabinet of Ministers of the Republic of Uzbekistan. This legal framework ensures that electronic waste from all regions of the country, after preliminary sorting at other enterprises, is directed to AMMC for further processing and the extraction of valuable metals. Such centralization of operations contributes to the formation of a unified recycling system at the national level, which strengthens Uzbekistan's industrial and environmental infrastructure.

A key component of this process is AMMC's Copper Smelting Plant, specifically the Gold and Silver Refining Workshop, which carries out the direct processing of electronic waste. According to the enterprise's chief engineer, the recycling process is based on the pyrometallurgical method, during which electronic waste is incinerated in special containers. This allows the safe removal of organic components while molten metals remain at the bottom, entering the plant's general metallurgical cycle. At subsequent stages, particularly during the electrolytic refining of copper, valuable elements such as gold, silver, and other precious metals are

successfully extracted from the sludge. This demonstrates the existence of a fully integrated production chain that includes smelting, electrolysis, and refining stages — a feature that distinguishes AMMC as one of the most technologically advanced metallurgical enterprises in the region.

Although the current volume of precious metal recovery from electronic waste is relatively small — for instance, in the first half of 2025, 312 tons of electronic waste yielded 10 kilograms of gold and 107 kilograms of silver — these figures highlight the potential for expansion and modernization rather than limitations. By introducing new hydrometallurgical and combined technologies, the extraction efficiency can be significantly improved. Moreover, such innovations would not only enhance the economic performance of the enterprise but also contribute to national goals for sustainable resource use and environmental protection. The enterprise's current reliance on the pyrometallurgical method, while effective for large-scale smelting, can be gradually supplemented by cleaner and more energy-efficient recycling technologies that ensure both safety and productivity.

At the same time, it is important to note that AMMC's approach to electronic waste demonstrates growing institutional awareness and commitment to circular economy principles. Although electronic waste currently represents an auxiliary source of raw materials compared to ore processing, this direction has promising prospects. Strengthening cooperation between Uztortsmet and AMMC, developing a steady supply chain of pre-sorted waste, and implementing government incentives for enterprises engaged in e-waste recycling will foster the establishment of an integrated, efficient, and environmentally responsible national recycling system.

Overall, AMMC's experience remains a valuable component of Uzbekistan's industrial ecosystem. It is currently the only enterprise in the country that performs the industrial-scale extraction of gold and silver from electronic waste, confirming its leadership in this field. The presence of advanced refining infrastructure and professional expertise creates strong prerequisites for further growth. With targeted investments, modernization, and adoption of advanced technological solutions, AMMC can significantly increase its metal recovery efficiency while minimizing environmental risks. In the long term, the enterprise can evolve into a regional center for electronic waste recycling, supporting both sustainable industrial development and environmental protection goals of the Republic of Uzbekistan.

The study of both enterprises' experience shows that the electronic waste recycling system in Uzbekistan is gradually forming as a multi-stage and integrated mechanism based on a combination of manual methods and industrial processes. At the first stage, implemented at JSC Uztortsmet, disassembly, sorting, and partial neutralization of electronic waste are carried out. The predominance of manual labor reflects the system's transitional nature and the existence of significant potential for mechanization and modernization. The current methods of mechanical separation ensure initial material classification and create a foundation for the subsequent introduction of automated technologies. The enterprise's operations play an important preparatory role, providing the primary filtering and organization of waste flows. The ongoing modernization efforts and future application of advanced sorting technologies will significantly enhance the efficiency of valuable material recovery. Additionally, as the system of household waste collection expands, the inflow of recyclable materials is expected to increase, strengthening the enterprise's resource base and production capacity.

The second stage of processing is conducted at the Almalyk Mining and Metallurgical Complex (AMMC), where the Gold and Silver Refining Workshop of the Copper Smelting Plant handles the recycling of electronic waste. Pyrometallurgical treatment and the subsequent integration of molten metals into the general metallurgical cycle ensure complete utilization of materials within an established technological process. At the stages of electrolysis and refining, gold, silver, and copper are extracted, confirming the presence of a closed, technologically consistent production chain. The enterprise's advanced metallurgical base provides the potential for improving quantitative performance indicators. In the first half of 2025, the enterprise processed 312 tons of electronic waste, obtaining 10 kilograms of gold and 107 kilograms of silver — data that demonstrate an initial operational capability and serve as a benchmark for further efficiency improvement. With the gradual implementation of hydrometallurgical and environmentally safe combined methods, these recovery rates can be significantly increased, contributing to both economic and ecological sustainability.

The comparative analysis indicates that the two enterprises perform interdependent and complementary functions within the national recycling system. Uztortsmet ensures the initial sorting, disassembly, and preparation of waste for industrial processing, while AMMC finalizes the technological cycle through the extraction and refining of valuable metals. This division of labor forms a structural basis for the development of a coherent and efficient electronic waste recycling network. The modernization of Uztortsmet's sorting systems and the enhancement of AMMC's processing capacities will further integrate the stages, ensuring higher productivity, improved metal recovery, and lower environmental impact.

The identified development priorities can be grouped into several directions. The first concerns technological advancement: Uzbekistan now has a foundational industrial base that can be strengthened by introducing modern mechanical, hydrometallurgical, and combined recycling methods to ensure safe and

efficient processing. The second direction involves infrastructure improvement: the existing collection system, which currently focuses on large organizations, can be expanded through public awareness programs and the establishment of permanent household waste collection centers in cities and districts. This will allow the redirection of significant volumes of household electronic waste from landfills into the recycling system. The third development area relates to economic and institutional motivation: increasing the profitability and strategic importance of electronic waste recycling for enterprises such as AMMC through targeted investments, fiscal incentives, and preferential lending mechanisms will help transform recycling into a stable and self-sustaining industry.

Thus, a comparative study of both enterprises demonstrates that Uzbekistan already possesses the fundamental infrastructure for electronic waste recycling and significant potential for its expansion. The main priorities for the near future include deep technological modernization, the establishment of an inclusive waste collection system, and the creation of favorable economic and legislative conditions that will stimulate industrial participation and innovation in this field. The gradual implementation of these measures will allow Uzbekistan to build a sustainable, resource-efficient, and environmentally responsible electronic waste management system that aligns with global standards and national development strategies.

The study of the activities of JSC Uztortsmet and the Almalyk Mining and Metallurgical Complex (AMMC) confirms that Uzbekistan already has a foundational infrastructure for electronic waste recycling and a strong basis for further development. The country's current achievements create favorable conditions for building a sustainable, efficient, and technologically advanced system. To ensure the full realization of this potential, it is necessary to implement a comprehensive set of organizational, technological, and social measures that will gradually elevate the sector to a modern industrial level.

First, priority should be given to the modernization of the technological base of recycling. At the stage of primary sorting, the introduction of automated mechanical lines for the separation of plastics, metals, and printed circuit boards will make it possible to significantly increase productivity and optimize the use of human resources. Such innovations will enhance precision in processing and improve overall efficiency. At the subsequent stage of valuable component extraction, the development and implementation of hydrometallurgical and combined technologies will ensure more complete recovery of precious metals from electronic waste, while minimizing environmental impact. Compared to traditional pyrometallurgical methods, these approaches provide safer and more sustainable solutions for both industry and the environment.

Second, the establishment of a modern, well-developed collection infrastructure for electronic waste represents a key direction for progress. Expanding the network of collection points in major cities, retail centers, and administrative districts will increase accessibility for the population and make the handover process simple and convenient. The implementation of digital tracking systems and incentive mechanisms can further encourage public participation. At the same time, promoting awareness through social media, educational programs, and mass media campaigns will strengthen ecological responsibility among citizens and encourage environmentally conscious behavior in society.

Third, stimulating enterprises' economic engagement in recycling will be decisive for ensuring long-term system sustainability. The gradual introduction of the extended producer responsibility mechanism, under which manufacturers contribute to the recycling of products at the end of their life cycle, will create a stable financial basis for the sector. In addition, state support through tax incentives, preferential loans, and targeted grants for the implementation of innovative technologies will make recycling economically attractive. This will help transform recycling from a purely environmental necessity into a profitable, innovation-driven area of industrial activity.

Fourth, strengthening cooperation between research institutions and industrial enterprises will accelerate technological advancement. Scientific research can provide innovative methods for waste neutralization, material recovery, and process optimization, while enterprises can offer a practical testing environment for these innovations. This synergy between science and industry will contribute to the formation of a national innovation ecosystem and facilitate the transition to high-tech, environmentally friendly recycling practices.

Fifth, the systematic development of environmental awareness among both the population and industry workers will further enhance the effectiveness of reforms. Educating citizens on the value of recycling and the potential harm of improper waste disposal will increase active public participation. For industrial employees, continuous training programs and ecological management practices will strengthen professional responsibility and foster a culture of environmental safety.

Thus, these comprehensive recommendations form a forward-looking roadmap for the development of electronic waste recycling in Uzbekistan. The integration of technological modernization, infrastructure expansion, economic incentives, and educational initiatives will create a resilient and efficient system capable of managing growing volumes of electronic waste. In the medium term, these efforts will not only ensure

environmental sustainability but also generate additional economic value for the country through resource recovery and the creation of new industrial opportunities.

CONCLUSIONS AND SUGGESTIONS

The study of the activities of JSC Uztortsmet and the Almalyk Mining and Metallurgical Complex (AMMC) confirms that Uzbekistan already possesses a foundational infrastructure for electronic waste recycling and demonstrates strong potential for further development. The existing framework provides an important starting point for establishing a sustainable and highly efficient system. To ensure the comprehensive realization of this potential, it is advisable to implement a coordinated set of organizational, technological, and social measures designed to improve performance at every stage of the recycling chain.

First, priority should be given to the modernization of the technological base of recycling. At the stage of primary sorting, the introduction of automated mechanical lines for separating plastics, metals, and printed circuit boards will significantly increase productivity and enhance processing precision while optimizing the use of labor resources. This transition will not only improve operational efficiency but also lay the foundation for the integration of smart technologies into the recycling process. At the stage of valuable component extraction, the gradual introduction of hydrometallurgical and combined methods will ensure a more complete recovery of precious metals from electronic waste and simultaneously reduce environmental risks. Compared to traditional pyrometallurgical techniques, these methods offer safer, more energy-efficient, and environmentally responsible solutions that align with modern sustainability standards.

Second, the development of a well-structured infrastructure for collecting electronic waste from the population represents one of the most promising directions for progress. The creation of easily accessible collection points in major cities and at retail locations that sell household appliances will facilitate public participation and improve logistical efficiency. Introducing user-friendly collection systems will encourage citizens to hand over unused equipment for recycling, while awareness campaigns conducted through social networks, educational programs, and media outlets will increase environmental literacy. These measures will gradually form a culture of responsible consumption and disposal, strengthening the foundation for sustainable waste management.

Third, fostering enterprises' economic interest in recycling will play a decisive role in transforming the sector into a self-sustaining industry. The introduction of the extended producer responsibility mechanism, which encourages manufacturers to participate in financing recycling at the end of product life cycles, will create a market-based foundation for sustainable growth. In parallel, state support in the form of tax incentives, subsidies, and targeted grants for technological innovation will help expand investment activity. This integrated approach will promote recycling as not only an environmental necessity but also an economically advantageous and innovation-driven area of industrial development.

Fourth, closer cooperation between scientific institutions and industrial enterprises should be expanded as a strategic direction for innovation. Scientific research in the field of waste management provides the intellectual and methodological basis for developing new technologies, while enterprises can serve as practical platforms for their implementation and testing. Strengthening this partnership will ensure a continuous exchange of knowledge, accelerating the introduction of advanced, eco-friendly, and cost-effective solutions. Such collaboration will also help create a national innovation ecosystem that supports sustainable industrial transformation.

Fifth, promoting environmental awareness among both the population and industry professionals is a key factor for long-term success. Increasing understanding of the environmental impact of improper waste disposal and emphasizing the economic and social benefits of recycling will enhance community engagement. Regular educational initiatives, professional training programs, and information campaigns will contribute to the formation of an environmentally conscious society, ensuring public support for national recycling strategies.

Thus, the outlined recommendations are aimed at further strengthening Uzbekistan's electronic waste recycling system through a combination of technological modernization, infrastructure enhancement, economic incentives, and educational initiatives. The consistent implementation of these measures will make it possible to form a sustainable, circular model capable of efficiently managing increasing volumes of electronic waste while generating additional economic value and contributing to the country's environmental stability. In the long term, these efforts will help position Uzbekistan as a regional leader in the field of sustainable waste management and resource recovery.

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