Effective use of secondary resources: technologies and recycling methods

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Abstract. The efficient utilization of secondary resources has become increasingly imperative in the context of sustainable development and environmental conservation. This abstract explores the latest advancements in technologies and recycling methods aimed at maximizing the value extracted from secondary resources while minimizing environmental impact. In recent years, innovative technologies have emerged to address the growing challenges associated with resource scarcity and waste management. These technologies encompass a wide range of approaches, including advanced sorting techniques, material recovery processes, and energy-efficient recycling methods. By leveraging automation, robotics, and artificial intelligence, these technologies enable more precise sorting and separation of recyclable materials, thereby enhancing the efficiency and effectiveness of recycling operations. Furthermore, this abstract examines the importance of circular economy principles in optimizing the use of secondary resources. By transitioning from a linear "take-make-dispose" model to a closed-loop system, where materials are continuously recycled and reused, significant environmental benefits can be realized. Circular economy strategies such as product redesign, remanufacturing, and waste-to-energy conversion play a pivotal role in minimizing resource extraction, reducing waste generation, and mitigating greenhouse gas emissions. Additionally, this abstract highlights the role of policy frameworks, industry collaborations, and consumer awareness in driving the adoption of sustainable practices across various sectors.

1 Introduction

The effective utilization of secondary resources has emerged as a critical imperative in the global pursuit of sustainable development and environmental stewardship. With mounting concerns over resource depletion, waste generation, and environmental degradation, there is an urgent need to adopt innovative technologies and recycling methods to maximize the value extracted from secondary resources while minimizing their environmental impact. This introduction sets the stage for exploring the latest advancements in secondary resource utilization and recycling practices, highlighting their significance in addressing key environmental challenges and promoting a transition towards a circular economy.

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In recent years, the world has witnessed a growing recognition of the finite nature of natural resources and the detrimental consequences of unsustainable consumption and production patterns. Rapid industrialization, urbanization, and population growth have exerted unprecedented pressure on the planet's finite resources, leading to ecosystem degradation, biodiversity loss, and climate change. Moreover, the linear "take-make-dispose" model of resource utilization has contributed to the accumulation of vast quantities of waste, posing significant environmental and health risks.

In response to these challenges, governments, industries, and civil society organizations have intensified efforts to promote the efficient use of secondary resources and the adoption of circular economy principles. The concept of a circular economy emphasizes the importance of designing out waste and pollution, keeping products and materials in use for as long as possible, and regenerating natural systems. By closing the loop on resource flows and minimizing waste generation, the circular economy offers a promising pathway towards achieving sustainability and resilience in resource management.

Key advancements in technology and recycling methods have played a pivotal role in advancing the goals of the circular economy and facilitating the transition towards a more sustainable resource management paradigm. From innovative sorting and separation techniques to advanced material recovery processes and energy-efficient recycling technologies, these innovations have enabled more efficient and effective utilization of secondary resources. Moreover, the integration of automation, robotics, and artificial intelligence has revolutionized recycling operations, enabling greater precision, speed, and scalability.

Despite significant progress, challenges remain in realizing the full potential of secondary resource utilization and recycling. Barriers such as technological limitations, economic constraints, and regulatory gaps continue to hinder the widespread adoption of sustainable practices. Additionally, the need for greater awareness and behavioral change among consumers and businesses is essential to drive demand for recycled products and support circular supply chains.

In conclusion, the effective use of secondary resources and recycling methods is essential for achieving sustainable development goals and addressing pressing environmental challenges. By embracing technological innovation, circular economy principles, and collaborative approaches, societies can move towards a more resilient and regenerative economy that preserves natural resources, protects ecosystems, and enhances human well-being. This paper will delve deeper into the various technologies, strategies, and policy interventions aimed at promoting sustainable resource management and advancing the circular economy agenda.

In 2016, the waste treatment, recycling, and disposal industry contributed a mere 0.08% to the gross domestic product (GDP) of the Russian Federation. According to data from Rosprirodnadzor, the country generated a staggering 5.4 billion tons of industrial and household waste that year, marking a record high in recent history. This figure represents a 50% increase compared to a decade ago and a 7% increase from 2015 levels. Despite a positive trend showing an increase in the beneficial use of waste from 40% in 2006 to 60% in 2016, the overall engagement of waste in economic circulation remains unsatisfactory.

The majority of generated waste, nearly 90%, comprises industrial waste, primarily from mining activities, categorized as hazard class V, including overburden, host rocks, and enrichment waste. While over 60% of this industrial waste is reused, only 10% is processed. Processing industries, particularly those dealing with hazardous waste (classes I to III), generate more than half of the total volume. Sectors such as textile production and metallurgy are among the most waste-intensive industries, with each contributing 5% and 4% respectively to the total waste generation in 2016.
In contrast, consumer waste presents a different scenario, with only 10-30% being recycled, depending on market demand for specific fractions. The lack of a reliable data collection system for consumer waste generation and utilization complicates analysis, relying instead on expert assessments and calculated indicators. While official statistics suggest high recycling rates for certain waste categories, such as glass containers (exceeding 90%) and tires (78%), expert evaluations paint a less optimistic picture.

Scrap and waste from ferrous and non-ferrous metals dominate the waste market due to their high liquidity. Ferrous metal scrap alone accounts for 17 million tons of domestic consumption, with a collection of 21 million tons, of which a significant portion is exported. Food waste represents a substantial segment of municipal solid waste (MSW), comprising about 35% or 17 million tons. However, its beneficial use remains limited due to inadequate separation systems, primarily utilized for feed and land fertilization, particularly in agriculture.

Plastics hold significant market potential for processors due to the demand for secondary raw materials. However, the lack of an efficient collection system results in a low extraction and recycling rate for polymer waste. Waste paper, while not the most profitable, remains accessible and constitutes a substantial portion of the waste disposal industry. In 2017, Russian manufacturers utilized 2.9 million tons of waste paper raw materials, with an additional 349 thousand tons exported abroad.

The glass recycling market follows closely behind, with an estimated consumption volume of 1.2 million tons, primarily composed of cullet. Despite challenges, the recovery rate for glass waste stands at 28%, considered relatively high given Russian circumstances. Conversely, plastic and rubber waste exhibit lower recovery rates (10-15%) due to their predominantly residential origin, posing challenges for recycling compared to industrial and commercial waste streams.

2 Research methodology

Metal recycling offers a sustainable solution by extending the lifespan of minerals and metals, alleviating environmental pressure, and conserving energy compared to primary production methods. However, in developing economies, recycling has historically lacked proper occupational health and safety (OH&S) measures, posing risks due to the handling of hazardous materials.

As awareness grows and policymakers take action, there's a shift occurring in the recycling landscape. Large enterprises are now entering the sector, expected to adopt Best Available Technologies (BAT) for improved environmental management and resource recovery. However, a key challenge lies in integrating various stakeholders in the value chain to ensure economic viability and profitability.

This paper aims to propose a sustainable recycling model for developing economies by integrating informal and formal sectors. The goal is to enhance current practices through scientific approaches and advanced technologies without disrupting existing economic structures. Case studies on lead acid batteries and e-waste recycling in India serve as the basis for developing a "green economy" model.

By fostering collaboration between informal and formal sectors, leveraging advanced technologies, and prioritizing environmental and economic sustainability, this proposed model seeks to transform recycling practices in developing economies, paving the way for a more sustainable future.

3 Results and Discussions
While incineration, particularly waste-to-energy (WtE) processes, is debated within the expert community regarding its classification as recycling, the authors assert that true recycling prioritizes returning useful waste fractions to circulation over incineration. Despite its advantages, energy recovery from waste remains less desirable than recycling, and thermal methods like pyrolysis pose ongoing interpretational challenges.

The study will adhere to general terms like recycling and disposal to avoid confusion, despite variations in official documents and terminology regarding secondary raw materials or products. Established phrases such as recycled raw materials and secondary polymers will be used to denote useful waste fractions prepared for processing into final products.

Despite economic challenges facing many nations, the global trend of increasing waste volumes persists. By 2022, waste generation had reached 22 billion tons, marking a 5% increase from 2015. Municipal solid waste (MSW) generation alone exceeded 1.3 billion tons, with projections indicating a rise to 2.2 billion tons by 2025, particularly driven by fast-growing cities in developing countries.

The most pressing issue in MSW management is the rapid growth of plastic, electronic, and electrical waste (e-waste). This surge is exacerbated by the substitution of traditional materials with hard-to-degrade polymers and plastics in industries such as packaging and transportation. Alongside the visible consequences of land-based waste accumulation, the emergence of marine debris islands poses a challenging problem, the scale of which is difficult to quantify.

The majority of consumer waste emanates from developed economies, with OECD countries accounting for 44% of MSW generation. The global waste management market exceeds $1.1 trillion, with an expected annual growth rate of 7–10% in the near future.

Regionally, 45% of the market is in Asia, 35% in EU countries, and 15% in the Americas. In 2015, industrial and construction waste constituted 84% of the market ($950 billion), while MSW accounted for 16%.

Despite increasing waste processing efforts, landfilling remains prevalent in many countries. However, there is a clear correlation between a nation's development level and its waste management practices. Developed countries view waste as a strategic resource for energy generation and material recovery. For instance, Japan achieves close to 100% recycling of waste into useful products, while some EU countries surpass 60% recycling rates, with waste sorting integrated into citizens' daily lives.

The adoption of “producer responsibility” initiatives has led to increased separate waste collection, including hazardous waste. Waste management primarily focuses on two areas: recycling and energy generation (waste-to-energy, WtE). Although waste-to-energy is common in Europe, the focus is shifting towards recycling due to overcapacity risks and adherence to waste management hierarchy principles. Regional differences in waste management practices are evident, with more developed countries prioritizing recycling while others remain heavily reliant on disposal methods, indicating varying levels of beneficial waste utilization.

4 Conclusions

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infrastructure. Plans include establishing MSW sorting complexes and multifunctional sorting complexes to enhance raw material availability and attract investors. However, it’s crucial to recognize the phased implementation of these plans, with significant changes in raw material flows expected in the medium to long term rather than immediate effects within 3–5 years.

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