The role of waste valorization in the transition to the circular economy

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Abstract

The circular economy consists of a system that proposes the full use of available resources, so that there is a significant reduction in waste generation, allowing them to be reinserted into the production chain, providing environmental, social, and financial benefits. The circular economy has the potential to offer an economic opportunity of $4.5 trillion, reducing waste, stimulating innovation, and creating jobs. Thus, waste valorization is identified as a key strategy to promote the circular economy, and meet the demands of a growing market focused on the preferential use of secondary raw material in production chains. Despite the numerous benefits related to the increase of practices related to waste valorization, one must take into account the existing barriers that hinder its implementation and popularization. The main barriers to the implementation of waste valorization in industries identified are: i) diversity of waste, ii) need for qualified professionals to perform this function, iii) environmental licensing for various operations, iv) high initial and operational costs for waste transformation, and v) the need for awareness and necessary cultural change within the business and political scope for valorization to actually occur.

Waste can have three major sources of generation: first, those generated post-consumption, which come from daily activities, called urban waste and which include domestic, commercial, and institutional waste. Secondly, there are wastes from agricultural activity, coming from animal breeding and food plantations (ASW, 2020). Lastly, there are wastes generated by various industrial activities which in turn result in waste with a wide variety of physicochemical characteristics (SDWF, 2016).

In Brazil, the NBR 10.004 standard, created by the Brazilian Association of Technical Standards, classifies all industrial waste into: Class I, hazardous waste; Class II, non-hazardous, being Class IIA non-inert and Class IIB inert. According to the NBR, hazardous industrial waste is that which presents risks to public health and also to the environment, while non-hazardous waste does not present these risks (ABNT, 2004). This classification is important to delimit the final destination of the waste, that is, if a waste can go to an industrial landfill, co-processing, or incineration, but with the application of transformation technologies these wastes can have more noble destinations, such as reinsertion into the productive process (EEA,2021).

According to ISO/FDSI 59004, "the circular economy is an economic system that uses a systemic approach to maintain the circular flow of resources, through the addition, retention, and regeneration of their value, contributing to sustainable development" (ISO, 2023). Thus, it aims at the reuse of materials that would be discarded in conventional waste disposal systems, such as industrial landfills or co-processing, and then applies them in regenerative cycles.

The approach proposed by the circular economy, when considering the reuse of waste as secondary raw materials, brings the following benefits:

Table 1. Benefits of the Circular Economy

Benefit	Example	Source
Environmental	The circular economy can significantly reduce the amount of waste generated and greenhouse gas emissions. A report from the United Nations Environment Programme (UNEP) states that a circular economy model could reduce industrial waste in some sectors by 80-99%, and emissions by 79-99%1.	(PNUMA, 2021)

Social	The circular economy can create jobs and promote social inclusion. Transforming waste into new products can create job opportunities at different stages of waste valorization.	(SCE, 2017)
Financial	By using fewer resources and reducing waste, companies can save on operational costs. In addition, transforming waste into new products can open up new market opportunities.	(OZILI, 2021)

Source: developed by the authors

According to the United Nations Economic Commission for Europe, waste valorization is one of the inputs to promote the circular economy (UNECE, 2024). A survey conducted by the United Nations Industrial Development Organization points out that the global trade of all types of waste showed positive growth from 2002 to 2019, demonstrating that there is a market for these products (UNIDO, 2021).

The circular economy can bring great opportunities and positive impacts to industries. According to the World Economic Forum, "The circular economy offers a $4.5 trillion economic opportunity by reducing waste, stimulating innovation, and creating jobs" (WEF, 2021). In addition, a report from the United Nations Environment Programme states that a circular economy model could reduce industrial waste in some sectors by 80-99%, and greenhouse gas emissions by 79-99% (UNEP, 2021).

In this way, the valorization of industrial waste can bring various benefits to companies, such as cost reduction, process optimization, and reduction of environmental impacts (KABONGO, 2013). However, the implementation of effective waste management strategies faces various challenges that make its application a lengthy process and hinders progress towards the implementation of the circular economy in practice. Some of the main challenges identified in the literature are presented in Table 2.

Table 2. Main challenges faced by the industry for waste management

Challenges	**Details**	**Source**
Diversity of waste	The diversity of generated waste is a significant challenge in proper management. Each type of waste requires a specific approach in terms of permanence, treatment, transport, and final disposal. Dealing with this diversity requires specialized technical knowledge and compliance with environmental regulations.	(NOGUEIRA; LINDELØV; OLSEN, 2023)
Operational costs	Proper management of industrial waste requires investments in infrastructure, equipment, personnel training, among other investments. These costs can be significant and represent a challenge for companies.	(ISWA, 2021)

Source: developed by the authors

Within the industry, there is the possibility of a single raw material going through a production process and generating different final products. Consequently, each final product from this first stage will generate a waste that is also different from the other, even in similar production systems, which is why it is so important to understand the whole production process and the waste generated at the end. An example of diverse industrial waste derived from a single raw material is calcium oxide, which is used in more than one stage in steel production in the metallurgical industry (MURRAY, 1991) to generate different products, as shown in Table 3.

Table 3. Uses of calcium oxide in the metallurgical industry

Impurity Removal	The ore is exposed to high temperatures in conjunction with calcium oxide, and the chemical reactions that occur in this process allow the formation of a liquid layer over the molten metal, which facilitates the removal of impurities.
Economy	The addition of calcium oxide to the steel alloy reduces its melting point, acting as a catalyst, which helps save energy/fuel used in the casting process and optimizes production speed.
pH Control	Added in a controlled manner, calcium oxide is capable of assisting in controlling the acidity and alkalinity of the steel during its production so that corrosion or other unwanted imperfections do not occur in the final result of the parts.

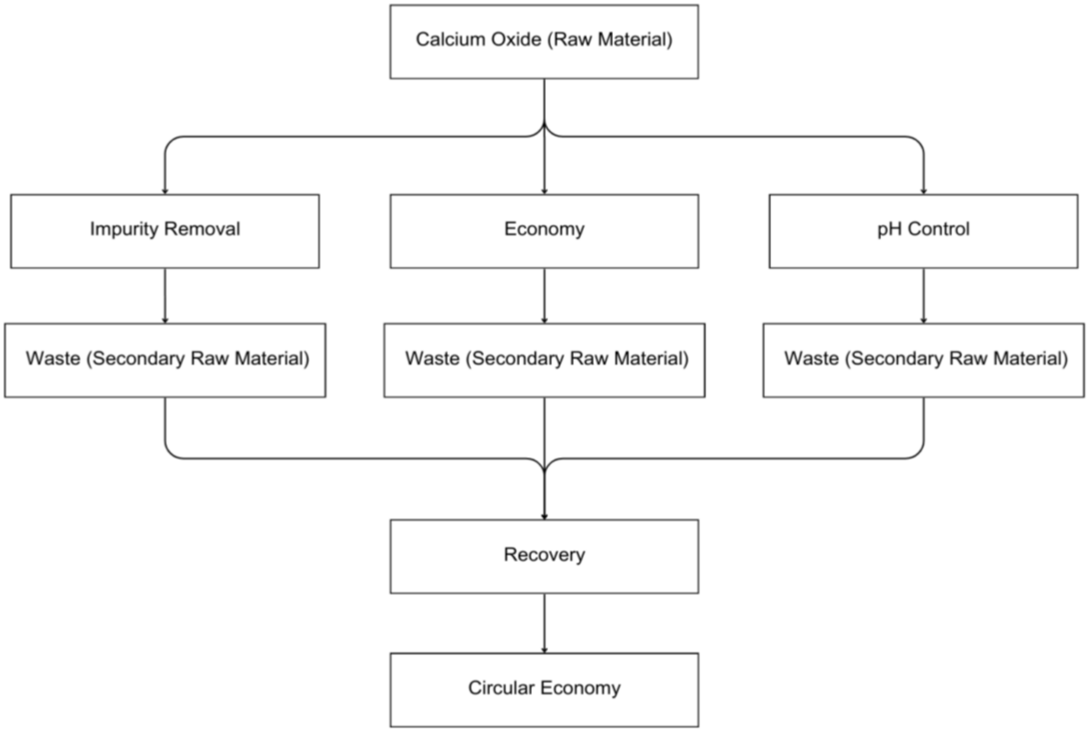
Source: developed by the authors

Each of the production stages, where calcium oxide is used, generates residues with different characteristics from each other, as seen in Figure 1, and which must be considered during the process of validating the possibility of valorizing this waste, and if so, the best way to apply such valorization, considering technologies, processes, consumer markets, complexities, and the need for qualified people for its development and operation (ORTH; BALDIN; ZANOTELLI, 2014). Given this, there is no standardized methodology that promotes the valorization of industrial waste, considering that each waste has its physical-chemical, biological characteristics, and specificities that make them unique.

One of the biggest obstacles to the application of valorization in industries is the lack of specialized professionals in the area to assist in the management of these wastes so that the company can achieve the circular economy. And that's why there are companies focused on research, development, and innovation for waste, like 4FeedStock, which aims to innovate and valorize waste, through its own methodologies.

It is recommended that waste be seen as a raw material not yet identified and that the first step for its valorization is its characterization, which aims to identify the composition and main physical, chemical, and biological characteristics with economic potential that provides attractiveness for the industry to actually carry out its transformation. The subsequent step is research, where all bibliographic review takes place, to know if there is already some study related to the waste or pre-existing routes. At this moment it is also very important to know the market as a whole, to evaluate if the chosen route has sufficient demand for acceptance of this waste as a product, so that the research can be scaled to an actual industrial activity.

Figure 1. Flowchart of calcium oxide stages



Source: developed by the authors

Conclusion

The global population growth, coupled with a significant improvement in living conditions and consumption patterns, will continue to pressure a growing demand for food, water, and energy resources, exceeding planetary boundaries, collapsing ecosystems, accelerating the loss of biodiversity, and intensifying the adverse effects of climate change. To ensure a prosperous future for future generations, it is essential that practices related to the circular economy are implemented and encouraged. For this, it is crucial to understand and map the existing challenges that hinder this movement. According to the literature, it is understood that the specificities of waste, operational costs, and lack of awareness are just some of the main barriers that slow down or make the valorization of industrial waste unfeasible. To overcome these challenges, we propose that: i) the characterization of waste is seen as a "key action" to understand waste as a secondary raw material with added value; ii) that new methodologies and business models emerge to meet the demand for innovative and technological solutions in the valorization of industrial waste; iii) that environmental awareness and education are encouraged to promote more sustainable initiatives mainly in the industrial scope; and iv) that public policies are designed to encourage and accelerate the implementation of more sustainable practices, generating positive impacts in industrial sectors, society, and the environment.

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