Valorization of Biomass Waste Materials, a Biorefinery Concept

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Oluwatoyin Joseph Gbadeyan,
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Fundamentals of Biomass Waste Valorization

Katleho Keneuwe Khoaele,[1]
Oluwatoyin Joseph Gbadeyan,[1]
Ipoteng Justice Mphahlele,[2]
Bruce Sithole[2] and Viren Chunilall.[1,2]
[1]Biorefinery Industry Development Facility, Council for Scientific and Industrial Research, Durban 4001, South Africa.
[2]School of Engineering, Discipline of Chemical Engineering, University of Kwazulu-Natal, Durban 4001, South Africa.

Abstract

The devastating impact of climate change and the necessity for sustainable products and processing approaches are significant concerns for the worldwide population. Interestingly, there is an abundance of biomass resources, which might meet the increasing demand for green products, as using fossil fuels is no longer recommended due to environmental concerns and sustainability. Biomass resources (renewable feedstock for renewable energy generation and specialty chemicals) are sourced from several natural sources and have a variety of applications. Most developed economies follow linear consumption concepts that are not feasible in the long term. The circular bioeconomy concept is a promising solution to minimize waste landfilling, generate revenue, and maximize zero-waste by utilizing biomass waste. The valorization of cellulose, lignin, and hemicellulose fractions into bioproducts, biofuels, or specialty chemicals depends on the practicality of their pre-treatment and further processing approaches. This chapter discusses biomass feedstock history, valorization processes, and

applications, and motivations for their exploration. Several value-added products, which can be harnessed from biomass and residues, are detailed.

Keywords: Zero-waste biorefinery, Biomass waste, Circular bioeconomy, Value-added products.

1.1 Introduction

The considerable rapid increase in the world's population and industrial production has resulted in prevalent disorder, including the impacts of climate change. The increased usage of fossil-based resources has worsened these disputes (Rahimi *et al.* 2022). The disposal, usage, and management of biomass waste is a growing problem for urban areas, particularly in developing nations, because of the output of biomass waste and a shortage of practical techniques for recovering these waste resources (Zhou and Wang 2020).

Most developed economies are based on linear consumption concepts. These models, sometimes known as "throw-away" or "take-make-dispose" models, are not feasible in the long-term (Khoaele, Gbadeyan, Chunilall, *et al.* 2023). At this moment, the environmental, economic, and societal consequences necessitate immediate action. In the circular bioeconomy concept, resources are utilized as much as possible, the highest value is extracted, and products are recovered and regenerated at the end of their lifespan (Jõgi and Bhat 2020; Khoaele, Gbadeyan, Chunilall, *et al.* 2023).

Circular bioeconomy is a zero-waste biorefinery that promotes green and economical waste disposal. Furthermore, bio-based industries have environmentally beneficial attributes such as non-toxicity, biodegradability, and biocompatibility, encouraging an eco-friendly trend. Bioprocesses that convert waste into value-added biofuels and biomaterials can significantly minimize reliance on fossil resources as feedstocks, preventing natural resource depletion. Biomass waste has been valorized into environmentally acceptable bioproducts such as medications, specialty chemicals, cosmetics, biofuels, biopolymers, and animal feed (Cheirsilp and Maneechote 2022; Romaní *et al.* 2020). The valorization of lignocellulose biomass into value-added bioproducts is an alternative to fossil resources as raw materials. This strategy aims to preserve the energy environment, mitigating greenhouse gas emissions such as carbon dioxide from burning fossil energy sources and minimizing carbon footprints (Dessie *et al.* 2023).

Conventional lignocellulosic biomass (LCB) is abundant in agro-industrial, forestry, and agricultural industries. Their examples are tree bark, sawdust, leaves, brewers spent grains, sugarcane bagasse, peels, shells, and husks such as wheat, sorghum, barley, rice, corn, oil palm stalks, straw, sunflower stems, switch grass, black liquor, waste papers, cotton residue, pomace, etc. (Ab Rasid *et al.* 2021). LCB consists of cellulose, lignin, and hemicelluloses, which exist in different quantities. Celluloses, the most abundant biopolymer, and renewable carbon substitutes, are linear homopolysaccharides of glucose linked by b-1, 4-glycosidic bonds. Hemicelluloses are a group of heteropolysaccharides made of b-1, 4 connected backbones of five sugars: L-arabinose, D-xylose (C5), D-glucose, D-galactose and D-mannose (C6) [9], [10]. Biomass feedstock can be recovered from nature as waste and can be categorized as follows in Figure 1.1 and Table 1.1.

Figure 1.1 Waste feedstock for zero-waste biorefinery (Maroneze *et al.* 2022).

Table 1.1 Biomass waste feedstock from various industries and their potential high-value products (Khoaele, Gbadeyan, Chunilalla *et al.* 2023; Gbadeyan *et al.* 2022; Tesfaye *et al.* 2017; Daroch, Geng and Wang 2013; Maragkaki *et al.* 2018; U. Lee *et al.* 2023).

Waste Feedstock	Biomass Type	Biomass Waste Resource
Agricultural Residues	Crop Residues	Non-edible components of crops such as rice, wheat, and corn are frequently abandoned in fields or burnt, generating greenhouse gases. These leftovers might generate bioenergy, make bio-based goods, or serve as fuel for biochemical processing.
	Straw	Straw from grains such as rice, wheat, and barley is widely regarded as agricultural waste. It may, however, be utilized for bioenergy, animal bedding, and mushroom growing as a substrate.
Food Processing Waste	Pomace	Fruit and vegetable pomace is produced during the juice and oil extraction operations and consists of skins, seeds, and pulp. These by-products can be exploited to create dietary fiber, antioxidants, and bioactive substances.
	Grape Marc	Winemaking waste like grape skins, stems, and seeds may be converted into high-value products such as bio-based chemicals, cosmetics, and dietary supplements.
Forestry Waste	Forest Residues	Branches, leaves, and other wooden residue are frequently left on-site or burnt during logging and forestry activities. These wastes might be utilized to produce bioenergy, charcoal, or bio-based compounds.
	Sawdust and Wood Shavings	Wood processing by-products are occasionally underused. They can be converted into heating pellets, animal bedding, or raw materials for bio-based products like biocomposites.

Aquaculture Waste	Aquatic Plant Waste	Water hyacinth or duckweed, which proliferate, can be utilized to generate bioenergy, feed animals, or recover nutrients.
Textile Industry Waste	Cotton Residues	Cotton stalks, seeds, and husks are frequently thrown away in cotton production since they are not used for textiles. These wastes might be utilized to produce bioenergy, biomaterials, or oil.
Municipal Solid Waste	Organic Waste	Organic waste from households and industries, such as food leftovers and yard debris, is frequently dumped in landfills. Biogas, compost, and bio-based goods might be produced by implementing effective organic waste sorting and conversion processes.
Aquatic Biomass	Algae	Algae may be utilized to produce biofuel, treat wastewater, and extract vital nutrients such as omega-3 fatty acids.
Pulp and Paper Mill Waste	Black Liquor	A by-product of the paper manufacturing process, black liquor, contains lignin. It may be used as an adsorbent for wastewater treatment, as an adhesive, and for energy generation through processes like black liquor gasification.
Brewery and Distillery Waste	Spent Grains	Grains such as barley and maize are discarded after brewing or distillation. These discarded grains can be utilized as animal feed, as a source of bioactive chemicals, or as a source of bioenergy.
Livestock Manure	Animal Manure	Animal manure may be converted into biogas and biofertilizers by anaerobic digestion, minimizing methane emissions.

Poultry Farming Waste	Feather Meal	Feathers, a by-product of poultry processing, generate feather meal, a protein-rich animal feed ingredient aiding nutrient recovery. Amino acids, keratin, and other proteins can be extracted for utilization in the cosmetics, pharmaceutical, and textile industries.
Aquatic Animal Waste	Shell Waste Utilization	Shellfish shells like oyster and mussel shells can be used for soil amendment and wastewater treatment. They can also trap carbon when used as shellfish cultivation substrates. Snail shells can be used as fillers to strengthen biocomposites.
	Collagen and Gelatin	Collagen isolated from aquatic animal waste can be utilized in the cosmetic, pharmaceutical, and food industries. Gelatin, a protein derived from aquatic waste, is utilized in confectionery and food products.
	Fish Processing Byproducts	Fish processing produces waste materials like heads, tails, and viscera, which can be processed for fish food and oil.
	Phosphorus Extraction	Aquatic animal waste can be a valued resource of phosphorus, an essential nutrient for plant growth. Phosphorus can generate nutrient-rich fertilizers.

1.2 History of Biomass

Biomass has long been used as a source of fuel, building materials, and food. Humans have depended on numerous types of biomasses for survival and development throughout history. An overview of the development of biomass use is depicted in Figure 1.2 below: