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## Beyond Waste: Integrative Biotechnological Pathways for Sustainable Recycling and Valorization of Industrial and Domestic Residues

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### Abstract

Waste accumulation from industries and households poses the greatest challenge to environmental sustainability and public health in industrializing and urbanizing nations. Conventional technologies for treating waste, including landfill and incineration, are increasingly coming under attack for their environmental disadvantages and poor resource recovery capacities. In this context, biotechnology offers itself as a paradigm-breaking technology for valorization of waste to value-added products. In this mini-review, advanced biotechnological interventions—ranging from microbial digestion and enzymatic depolymerization to anaerobic fermentation and bio-electrochemical systems—are presented for recycling and valorization of heterogeneous waste streams. Emphasis is on engineering microbial consortia, synthetic biology for designing engineered enzymatic activity, and interfacing of bioprocesses with digital monitoring systems. Examples of case studies are microbacteria degrading plastics, upgradation of lignocellulosic biomass, biofuel, bioplastic, and organic fertilizer manufacturing. Reviewing also includes socio-economic and policy frameworks required for the adoption of bio-based circular economies, especially in low- and middle-income countries. Biotechnology offers relief to the environment as well as employment generation and propelling green innovation with furthering cross-disciplinary approaches and bridging the waste-resource gap.

**Keywords:** Biowaste valorization, Microbial recycling, Industrial biotechnology, Circular economy, Waste-to-resource, Sustainable waste management

