Research Journal of Engineering Sciences ISSN 2278 – 9472
Vol. **14(1),** 41-46, January **(2025)** *Res. J. Engineering Sci.*

Review Paper

A Systematic review on Recent Trends and Emerging - Circular Economy

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Available online at: www.isca.in, www.isca.me
Received 25th July 2024, revised 13th Octomber 2024, accepted 16th November 2024

Abstract

Our planet is facing numerous environmental and ecological problems due to increased economic activities and development processes. A major portion of these environmental problems are related to waste in production sectors such as textile, construction, and packaging. A significant part of the solid waste is non-biodegradable which induces hazardous chemical extraction processes. Burning of such waste products results into toxic gas emissions into the atmosphere. This has led to extreme pollution of the soil, rivers, and the sea. Due to the non-biodegradable nature of the waste, it takes hundreds of years to decompose naturally. However, the concept of circular economy shall be considered a high-yielding remedy to the existing issues associated with solid waste management. It can also strengthen the approach to sustainable development. In this study we provide a literature review on recent developments in the up cycling of different types of solid wastes, potential emerging technologies and new opportunities for a sustainable environment. The study presents strong association of circular economy, sustainable production and waste management. Also it offers a thorough view of the potential significance and current commercial applications of the developed biobased materials in relevant areas such as packaging, construction and textile. The review also discusses evolution of circular economy by ways of designing of new products and enacting of new regulations for industries to embrace it. The movement towards circular economy stems from aspirations to tackle urgent environmental issues, cultivates financial success, alleviate the effects of climate change, advance social justice and safeguard the welfare of current and future generations. It signifies a pattern change towards method of manufacturing and consumer behavior that are more fair, regenerative and sustainable.

Keywords: Sustainable development, Circular economy, Waste recycling, Solid waste management, Biobased materials.

Introduction

Population growth, unsustainable consumption patterns and the current profit-driven linear economic systems result in uncontrolled solid waste production[1]. Solid wastes can be majorly classified as biodegradable and non-biodegradable where paper, cardboard, animal/plant wastes as well as several other organic wastes fall under the category of biodegradable wastes while plastic and metallic wastes are of the non-biodegradable type. Urbanization, industrialization and economic growth have resulted in increased municipal solid waste generation per person[2]. The accelerated global consumption growth of goods has resulted in the overexploitation of natural resources[3]. Over the last 40 years, paper consumption has increased by 400 % globally, leading to deforestation, and 35% of felled trees are used to produce paper[4]. Plastic has evolved into a symbol of human inventiveness as well as folly which is an invention of extraordinary material with a variety of characteristics and capacities[5]. Management of Industrial metallic waste is also a strenuous problem that results into soil depletion and degrades soil quality. The quantities of waste being produced at a rapid rate represent a challenge for all the nations across the world, but at the same time it is an opportunity to alleviate problems of material (and, partially, of energy) scarcity[5]. The sustainable management of MSW is a multidisciplinary problem that connects the social, environmental and economic pillars of sustainability[6]. The circular economy is a concept that promotes the repair, improvement and redistribution of second-hand goods. Circular economy is basically an idea, which drives the change of a linear process into a circular process, which involves reduction, reuse, recycling, arrangement, assembly and circulation[7,8]. In this perspective, use of the ‘‘3Rs’’ (i.e., reduce, reuse, recycle) may lead to a competitive advantage[9].

By and large, Circular Economy is based on: design of manufactured products with added value and maximum use in longer life cycles; creation of versa- tile products with different uses, in different periods of their useful life, thus guaranteeing the reuse of a single good; restitution of solid waste to the industrial sector in an orderly manner, where the cost of secondary raw materials from recycling is competitive in the market; as well as a systemic approach to supply chain management, evaluating the inter- connections between the energy produced, the extracted material, and the natural environment[10,11]. With this view, the present review aims to provide a detailed information regarding different types of solid wastes and their composition, the approaches employed by various nations for management of these solid waste products. The work also gives insight on how this impacts the circular economy around the world through an overview of the most up-to-date and relevant scientific publications on the topic, with the specific objective of a systematic literature review.

Solid waste types and composition

Solid waste refers to any discarded or abandoned material that is not liquid or gaseous. In the context of solid waste management, solid waste generated by different sources can be categorized as following[12]:

Municipal Solid Waste: Waste that is generated by households, hotels, markets, offices, institutions, and other non-industrial sources. This includes organic waste, paper, plastics, glass, metals, and other miscellaneous items.

Industrial Waste: This is generated by several manufacturing and industrial processes. In addition to a very low quantity of organic waste it includes hazardous and non-hazardous waste, such as chemicals, solvents, metals, and by-products from industrial activities.

Biomedical Waste: This type of waste is generated from hospitals, clinics as well as research centers. It includes infectious waste, pharmaceutical and pathological waste.

Construction Waste: This is generated during construction, demolition activities as well as during renovation process. It includes waste materials like concrete, bricks, wood, metals, plastics, and packaging waste.

Electronic Waste: Also known as e-waste, it comprises discarded electronic devices such as computers, mobile phones, televisions, and other electrical equipment. This type of waste is mostly metallic in nature.

Hazardous Waste: Waste that poses substantial risks to human health or the environment due to its chemical or physical properties. Examples include toxic chemicals, pesticides, and radioactive materials.

Agricultural Waste: Generated from agricultural activities, such as crop residues, animal waste, agrochemicals, and packaging materials used in farming

Recycling methods/technologies

The informal sector is vital in India, and it must be integrated into official SWM systems[13-15]. The informal sector is described as smaller, laborious, largely unsupervised and unlicensed low-technology production or supply of goods and services[16].

Segregating garbage at the source reduces contamination and allows for easier collection and transportation for processing. It also optimises waste processing and treatment methods, resulting in a high proportion of separated material that may be reused and recycled, reducing the consumption of virgin material. i. At the home level, MSW should be divided into wet, dry, and domestic hazardous waste components and kept in separate containers. ii. Waste should be put at the door prior to the scheduled collection hour. iii. To ensure safe disposal, household hazardous trash, including batteries, tube lights, chemicals, paint, and pesticide containers, should be sent separately to garbage collectors or disposal sites. iv. Sanitary waste, including diapers, sanitary napkins, tampons, and incontinence sheets, should be properly packed in pouches and given over to trash collectors on a regular basis[17-19].

BASIC SEGREGATION				
Wet waste (green bin)	Dry waste (Blue bin)			
	With further sub-segregation BASIC+			
Food wastes of all kinds, cooked and uncooked, including eggshells and bones, flower, fruit and waste including juice, vegetable peels and household garden/plant wastes. Soiled tissues, food wrappers, paper towels; fish and meat	Paper cardboard and cartons	Containers & packaging of all kinds excluding those containing hazardous materials Compound packaging (tetrapak, blisters etc.) Plastics	Rags Rubber Wood Discarded clothing Furniture	Metals Glass (all kinds) Inerts House sweepings and inerts (not garden, yard or street sweepings)

Figure-1: Segregation of waste[17-19].

Increased waste-to-energy conversion would minimise land disposal while also producing clean, dependable electricity from a sustainable fuel source, lowering reliance on fossil fuels and GHG emissions. Recycling. Recycling transforms wasted materials into new goods, minimises landfill volumes, and lowers consumption of fresh raw materials, energy use, GHG emissions, and dangers[20].

Management of non-biodegradable waste: Recycling recovers and reprocesses useable materials that would otherwise become garbage. The recovered material may be converted into valuable goods, reducing the need for virgin resources in manufacture. Using recycled materials saves energy compared to producing using virgin resources. This approach reduces energy consumption and greenhouse gas emissions throughout the product lifespan, including extraction, production, and decomposition[8]. Common recyclable materials include paper, cardboard, glass, plastics, and metals. Combustible dry solid waste may be converted into energy through three methods: refuse derived fuel, gasification and incineration. These methods also come under 'Waste to energy' category which means generating heat or electricity from solid waste[17].

Refuse Derived Fuel (RDF): Waste which is a non-recyclable and non-hazardous material with a high calorific value that may be utilised to recover energy through burning. To maximise energy output, the garbage is shredded, dried, and compacted into pellets or briquettes known as Refuse Derived Fuel (RDF)[17,20].

Gasification: Processes such as pyrolysis, gasification, and plasma-gasification convert high-calorie dry waste into valuable products such as syngas, ethanol, and bio-char, among others. Gasification, as the name implies, transforms much of the carbon in any substance into gaseous form when heated in the presence of oxygen under regulated conditions. The resulting gas, known as synthesis gas or syngas, has a variety of uses, including energy generation. Plasma-gasification, which occurs at temperatures ranging from 480°C to 1650°C, requires even higher temperatures (≥ 2760°C) and is not yet demonstrated for municipal trash. Pyrolysis, on the other hand, occurs at relatively low temperatures (300°C to 760°C), but without oxygen, yields liquid fuel, char, and gases such as carbon monoxide, hydrogen, and methane. The country currently has a few tiny yet functional projects in existence[20].

Incineration: In India, mixed trash is commonly incinerated without pre-processing to reduce volume and create heat energy. This technique poses a danger of releasing harmful gases into the environment, especially when feedstock waste contains heavy metals, PVC, and other halogenated chemicals[20].

Unscientific Solid Waste Disposal: Sanitary landfills are designed pits with a covered bottom and side liners that bury unrecoverable, stabilised garbage in layers. To reduce space, the trash is compressed and coated with an inert layer, which includes vents for gas escape and a bottom drainage network for leachate collection and treatment[20].

Management of bio-degradable Waste

Composting: Composting is a biological process where organisms transform organic materials into compost. Organic waste decomposes naturally, emitting gases such as methane or CO_2 according on the aerobic state[10]. Composting is the controlled breakdown of organic waste under aerobic conditions, producing stable humus-like compounds known as compost. Composting is a crucial component of municipal solid waste management (MSWM) in India due to its typical waste composition and climatic circumstances[17,20,22].

Bio-methanation: Bio-methanation is another 'Waste to energy' method of anaerobic fermentation of biodegradable waste in a controlled environment. In the absence of oxygen, microorganisms break down organic materials, releasing biogas that contains methane. The petrol can be used instead of traditional fuels such as LPG or CNG. It may also be condensed and bottled into compressed biogas (CBG), which can then be transformed into power using generators, producing a 30% conversion efficiency. However, over 70% of the energy is wasted as heat during conversion. Bio-methanation produces slurry, which is a good liquid manure for agriculture. Bio-methanation therefore not only generates energy but also provides nutrients to soil[20]. Large amounts of garbage are often treated using either bio-methanation or composting technologies to produce biogas, energy, and compost. Biogas contains 55-60% methane and may be utilised as a fuel for power generation. Aerobic composting and vermicomposting are the most frequent methods for treating biodegradable waste. This compost is used to raise vegetables and plants on homesteads[23]. Manufacturing of bio-based materials: Plant and animal waste are utilised as raw materials to create bio-based goods. Utilising trash from these sources provides the benefit of obtaining materials from renewable sources. This strategy offers an ecologically benign option to managing residue, perhaps reducing its impact[24-27].

The strategic addressing of solid waste management through the circular economy is crucial for achieving sustainable and efficient waste practices. The circular economy model offers a transformative approach to waste management by shifting from the traditional linear "take-make-dispose" model to a more sustainable system that focuses on minimizing waste generation and maximizing resource efficiency. By incorporating circularity principles like recycling, reusing, remanufacturing, and refurbishing, the circular economy promotes the idea of keeping materials and products in use for as long as possible[28]. Reducing waste at its source is the most effective way to cut costs and environmental impact. It covers actions to decrease waste from product manufacture and consumption. It also includes efforts that improve product durability, reusability, and reparability[17,23,30].

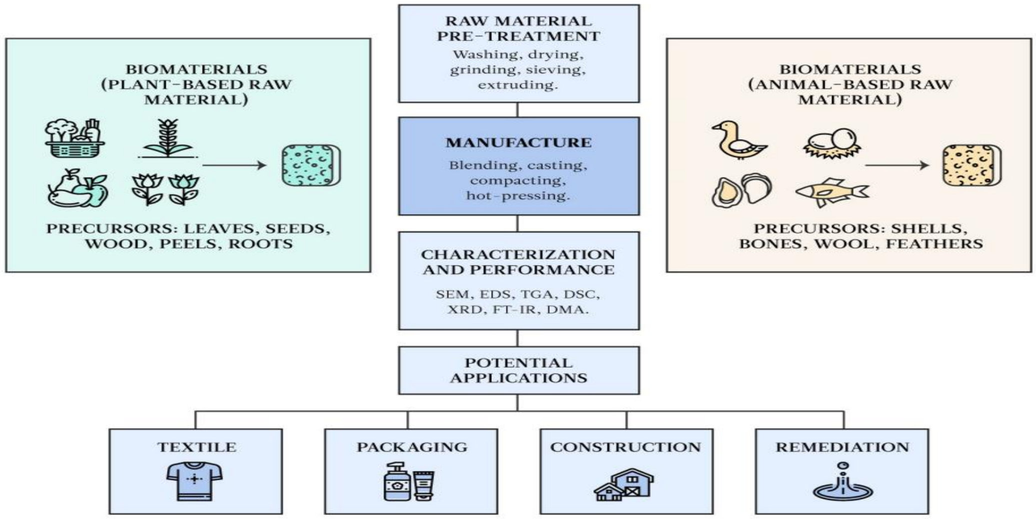

Figure-2: General approach, characterization methodologies, and probable uses for bio-based products derived from plant or animal waste[27].

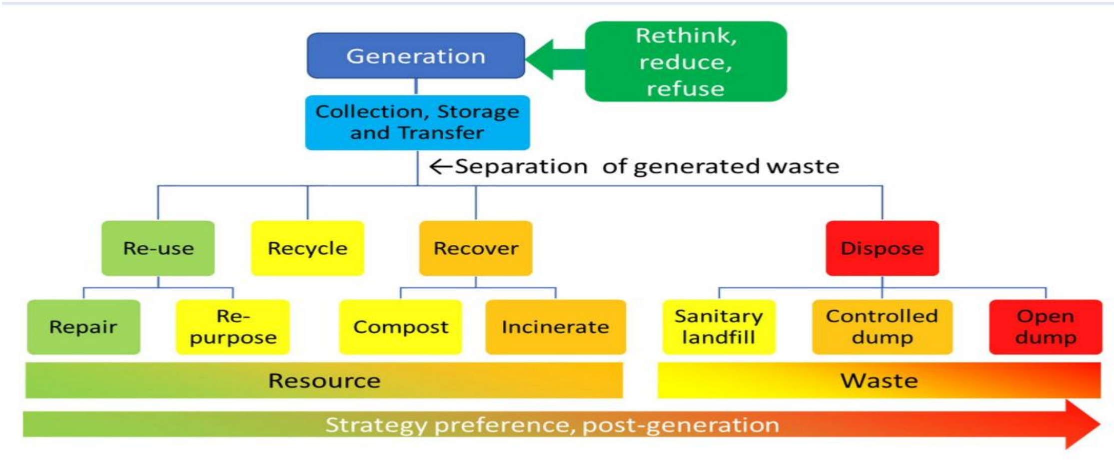

Figure-3: Addressing waste management practices before and after waste generation and separation. The order of preference for generated wastes moves from left to right[29].

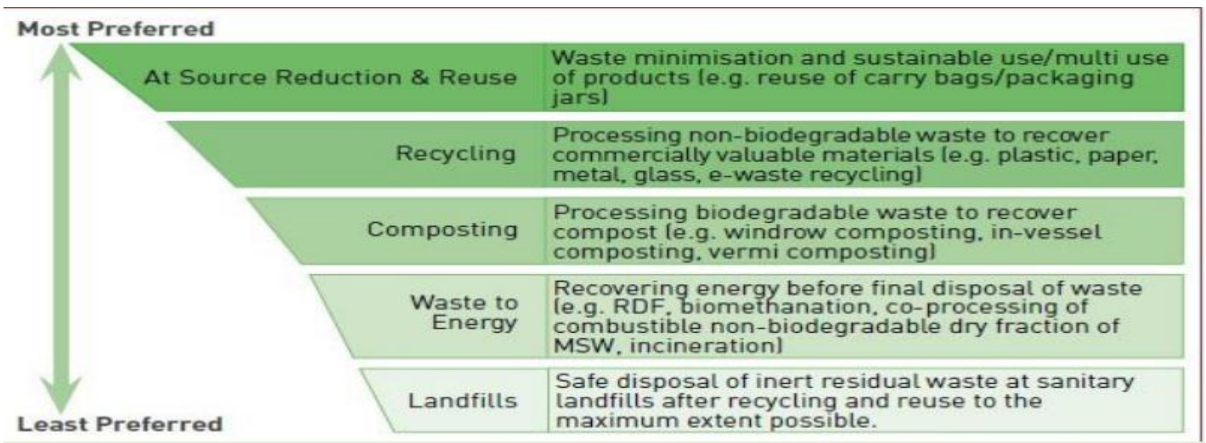

Figure-4: Waste management[17,23,30].

Conclusion

The concept of a circular economy has gained significant traction in recent years as a more sustainable and efficient alternative to the traditional linear economy. A circular economy aims to transition from a 'take-make-waste' approach to a more restorative and regenerative system, focusing on eliminating waste and pollution, keeping products and materials in use, and regenerating natural systems. This shift is crucial due to the urgent need to address environmental degradation, resource scarcity, and the negative impacts of human activity on the planet.

Therefore, transitioning to a circular economy is vital for achieving long-term sustainability, economic prosperity, and environmental well-being. By embracing the principles of reducing, reusing, and recycling, businesses, governments, and individuals can work together to create a more efficient, sustainable, and prosperous future for all.

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