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Recent Advancements in Utilization of Municipal Solid Waste for Invention of Bioproducts: Framework for Low-Income Countries

[1]Arun Kumar Mohanta, [2]Biswajit Patra, [2]Saroj Kumar Deep, [3]SK Imran Ali, [2]Surya Narayan Pradhan, [1]Chittaranjan Sahoo

[1]Indira Gandhi Institute of Technology Sarang, Utkal University, Bhubaneswar, Odisha, India
[2]School of Life Sciences, Sambalpur University, Odisha, India
[3]Department of Chemistry, University of Kalyani, West Bengal, India
patrabiswajit090@gmail.com

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Abstract

In developing countries, the generated waste is simply disposed of in an open area, which causes a severe threat to humans, animals, and the environment. To date, organic waste and fourth-generation biomass have been investigated for multiple targeted products. Thus, the present review article highlights the emerging problems in organic waste generation, management, and converting them into various value-added bioproducts. This review also deals with the conversion of multiple biofuels such as liquid, solid, gaseous, and bioelectricity from organic waste resources. Besides, the latest approaches in organic waste are also addressed for the production of value-added bioproducts such as bioplastic, bio-compost, and organic acids in detail. Furthermore, the techno-economic analysis and life cycle assessment of organic waste is also explored. The transformation of organic waste to value-added bioproducts enhances the circular bioeconomy approach by reducing waste, increasing energy production, and other healthcare products. Finally, it is concluded that the utilization of organic waste to value-added bioproducts and biofuels production will be helpful in achieving high energy security, environmental protection, as well as enhancing the bioeconomy perspective.

Keywords: Solid waste, bioplastic reduce, management, landfill, compost

Introduction

Municipal Solid Waste Management (MSWM) is one of the key challenges created by population and prosperity, representing the two critical drivers for waste generation in any economy. Significant increase in waste generation, lack of both the sustainable waste management plans and their implementation policies, are accountable for causing environmental damages like soil, water and air pollution, plant and animal contamination, and generation of odors [1]. Waste ending in landfills causes littering and emission of greenhouse gases responsible for causing health related problems along with environmental damages worldwide, the developing economies have witnessed the trend of rural population migrating to urban areas for employment, better facilities, and convenience [2,3]. This has led to a significant increase in the generation of municipal solid waste (MSW). Management of MSW and its valorization are among the major challenges of growing urban economies [4]. This study focuses on the trend of MSW generation, its characterization, segregation, and bibliographic review of its utilization in the development of bioproducts. The waste generated per capita significantly varies from region to region with the Unites States of America reporting a higher waste generation of 2.21 kg/individual as compared to Europe and Central Asia (1.18), Latin America and the Caribbean (0.99), Middle East and North Africa (0.81), East Asia and Pacific (0.56), South Asia (0.52) and Sub Saharan (0.46) respectively. MSW generated in urban developments is positively correlated to urban per capita disposable incomes [5,6].

Waste Management in Developing Countries

The generated waste damages the environment by contaminating the water, soil, and air, thus affecting the natural flora and fauna. The mismanagement of waste can also jeopardize human health; hence, it is important to have sustainable waste management plans [7]. The sustainable waste management hierarchy is waste prevention and reuse followed by recycling and other recovery operations over disposal [8]. Developed countries have more resources, educated people, and a strong economy to support, plan, and implement sustainable waste management plans. Urban waste management is a major challenge due to the heterogeneity of raw materials, impeding its utilization. The segregation of urban waste is vital for its optimal utilization [9].

Waste Characterization

The segregation of MSW at collection level is suggested as the most efficient and optimal solution for sustainable urban waste utilization. Separate collection of waste helps achieve garbage reduction, resource utilization, and prevention of environmental degradation. Several studies are reported on the use of different models for separation and classification of waste [10]. For example, the mechanical separation of different materials such as cardboard, glass, metal, paper, and plastic with the "bin based" prototype, designed on the application of a machine learning and neural network model, reported an accuracy of 92.1

Utilization of Segregated Solid Waste

MSW is traditionally used in composting, incineration, anaerobic digestion, and landfills, whereas recent research studies are more focussed on the biorefinery approach involving the development of a broad range of products with minimum energy requirements and waste generation [12]. There are potential opportunities for the utilization of MSW in development of biopolymers, biofilms, and other similar products. The incineration of MSW causes the loss of high-value bioproducts and produces pollutants in the environment. The most prevalent method used for the valorization of MSW involves the production of biofuels, organic acids, and volatile fatty acids (Figure 1) [13-16]; limited research is available for the production of bioproducts such as biomaterials, bioplastics, biopesticides, and biosurfactants from MSW (Tables 1 and 2).

Agricultural Waste Management

Organic wastes are high in nutrients and organic matter, making them a useful source of manure for agricultural land, biogas production, soil erosion prevention, mulching, and other uses. They have also been employed in biorefineries in recent years. Agricultural wastes are utilized as cow fodder, compost, cooking fuel, and a great choice of bioenergy conversions with established technology [17]. The fundamental fuel for anaerobic digesters is agricultural biomass such as manure, slurry, silage, and harvest byproducts. Organic wastes can account for up to 80% of a farm's total solid wastes, with manure production reaching 5.27 kg/day/1000 kg live weight on a wet weight basis. Food processing businesses such as juice, chips, meat, candy, and fruit produce a large number of organic wastes and produce effluents every year [18]. These organic wastes can be used to generate various types of energy sources. As the world's population grows, the demand for food and other resources increases. Therefore, numerous food and beverage sectors have grown significantly in most nations in that region to meet the growing need for food. As a result, many industries release millions of tons of hazardous material into the environment each year. During each processing stage, industries generate a huge amount of wastewater and sludge [19]. Industrial waste is difficult to generalize since its qualities vary from industry to industry and from processing plants. Papermill sludge, meat processing waste, brewery wastes, and textile mill fibers are all part of the organic fraction of industrial waste [20]. Due to the high levels of organic compounds in some treated industrial waste waters and sludges, they can also be employed as soil fertilizers and amendments.

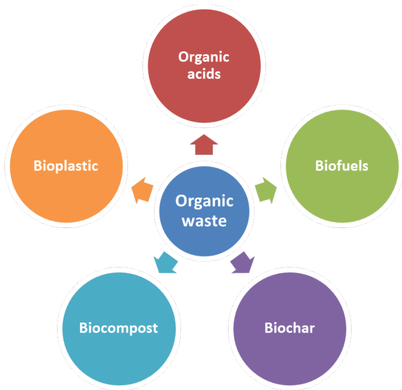

Figure 1: Diagrammatic illustration of organic waste to multiple bioproducts and biofuels.

Biocompost Production

The superior organic-based biofertilizers could be produced from the organic waste source through bioconversion technology to improve soil fertility and increase crop yield. The transition of using chemical fertilizers to bio-based organic fertilizers has gradually increased in recent years due to the benefits of chemical-free, high nutrient organic food crops [21]. These biofertilizers contain indispensable mineral nutrients such as nitrogen, potassium, phosphorous, magnesium, calcium, and other organic species to enhance the soil content of organic matter, which could replace the hazardous synthetic chemical fertilizers. The biofertilizers could be derived mainly from the organic waste source of plant biomass, animal sources having live microbial agents that exhibit many functions for aiding nutrient replenishment, soil amelioration, and soil conditioning for efficient crop production with high yield. Algae biomass and wastewater-based algal biomass are providing essential nutrients supply as stimulators to enhance bioavailable mineral concentration in the soil for plant growth and crop fortification and restrict pathogens for the dual benefits of increased economic food grain production and environmental waste remediation [22-24]. The biostimulants are bioactive compounds with natural raw materials formulations depending on the source of extraction. Biostimulants can be classified into two types such as microbial biostimulants (fungi, bacteria, fermented organic waste) and non-microbial biostimulants that include amino acids, protein hydrolysates, peptides, seaweed extracts, and humic substances [25-27].

Table 1: Source of Agriculture Waste and Its Major Compositions [28,29]

Organic waste	**Lignin (%)**	**Hemicellulose (%)**	**Cellulose (%)**
Flax straw	22.6	27.5	29.1
Pine sawdust	27.3	24.5	21.4
Chickpea straw	33.5	22.4	22.7
Oak sawdust	12.6	12.7	27.5
Barley straw	11.6	23.6	11.3
Cattle manure	22.8	21.4	23.5
Tea residue	25.8	25.7	21.4
Banana residue	24.7	24.1	25.6
Rice husk	15.9	23.8	28.9
Newspaper	16.2	25.1	25.6
Chemical pulps	17.4	14.7	21.3
Swine waste	19.5	18.3	26.1
Oil effluent	24.1	19.3	23.5
Vegetable peel	18.3	14.7	22.9
Fruit peel	19.5	17.2	10.9

Table 2: Different Activities toward Sustainable Solid Waste Management in Low-Income Countries

Sl No	Recent Activities for Solid Waste Management	References
1	Long-term effects of organic amendments on soil fertility	[30]
2	Biomass combustion in fluidized bed boilers: Potential problems and remedies	[31,32]
3	Heavy metal driven co-selection of antibiotic resistance in soil and water bodies impacted by agriculture and aquaculture	[33–35]
4	Carbonized chicken eggshell membranes with 3D architectures as high-performance electrode materials for supercapacitors	[36]
5	Recovery of precious metals through biosorption	[37]
6	Organic fertilizer as a vehicle for the entry of microplastic into the environment	[38]
7	A versatile biomass derived carbon material for oxygen reduction reaction, supercapacitors and oil/water separation	[39]
8	Recent advances in applications of activated carbon from biowaste for wastewater treatment	[40–42]
9	Microbiological aspects of biowaste during composting in a monitored compost bin	[43]
10	High surface area activated carbon from rice husk as a high-performance supercapacitor electrode	[20]
11	Suppressiveness of 18 composts against 7 pathosystems: Variability in pathogen response	[44]
12	Effect of temperature on hydrolysis rates of selected biowaste components	[45]
13	The chemomechanical properties of microbial polyhydroxyalkanoates	[46]
14	A review of survival of pathogenic bacteria in organic waste used in biogas plants	[47]
15	Bacterial diversity at different stages of the composting process	[48,49]

Sl No	Recent Activities for Solid Waste Management	References
16	A technological overview of biogas production from biowaste	[6]
17	Converting biowaste corncob residue into high value added porous carbon for supercapacitor electrodes	[8]
18	Mesophilic and thermophilic anaerobic digestion of source-sorted organic wastes: effect of ammonia on glucose degradation and methane production	[14]
19	Identification and quantification of macro- and microplastics on an agricultural farmland	[50]
20	Biowastes-to-biofuels	[51]
21	Multistage optimization of the supply chains of biofuels	[52,53]
22	Development of a new Cr(VI)-biosorbent from agricultural biowaste	[54,55]
23	Nitrogen in biowaste and yard waste compost: dynamics of mobilisation and availability	[56–58]
24	Fabrication and characterization of hydrophilic corn stalk biochar-supported nanoscale zero-valent iron composites for efficient metal removal	[52,53,59]
25	Strategies for the anaerobic digestion of the organic fraction of municipal solid waste	[54–57]
26	Effect of compression ratio on performance, combustion, and emission characteristics of a dual fuel diesel engine run on raw biogas	[2]
27	Effect of ammonia on the anaerobic degradation of protein by a mesophilic and thermophilic biowaste population	[4,5]
28	Prokaryotic successions and diversity in composts as revealed by 454-pyrosequencing	[8]
29	Apple-biowaste-derived hard carbon as a powerful anode material for Na-ion batteries	[10]
30	The emission of volatile compounds during the aerobic and the combined anaerobic/aerobic composting of biowaste	[9]
31	Soil aggregate stability improvement with urban composts of different maturities	[11]

Sl No	Recent Activities for Solid Waste Management	References
32	Bioethanol supply chain system planning under supply and demand uncertainties	[16]
33	Biochar farming: defining economically perspective applications	[60]
34	Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment	[61]
35	Biotechnology and the utilization of biowaste as a resource for bioproduct development	[62,63]
36	Production and applications of activated carbons as adsorbents from olive stones	[28,64]
37	Oil palm waste: An abundant and promising feedstock for microwave pyrolysis conversion into good quality biochar with potential multi-applications	[65–67]
38	Domestic waste composting facilities: A review of human health risks	[52,59]
39	Critical factors in chitin production by fermentation of shrimp biowaste	[53,54]
40	Mesophilic and thermophilic anaerobic co-digestion of waste activated sludge and source sorted biowaste in pilot- and full-scale reactors	[68]
41	Degradation of natural and synthetic polyesters under anaerobic conditions	[69]
42	Optimization of two-phase thermophilic anaerobic digestion of biowaste for hydrogen and methane production through reject water recirculation	[6]
43	Flexible and anti-freezing quasi-solid-state zinc ion hybrid supercapacitors based on pencil shavings derived porous carbon	[10]
44	OPAC (orange peel activated carbon) derived from waste orange peel for the adsorption of chlorophenoxyacetic acid herbicides from water	[15]
45	Food waste valorization via anaerobic processes	[70]
46	Pyrolysis characteristics and kinetic studies of horse manure using thermogravimetric analysis	[60]

Sl No	Recent Activities for Solid Waste Management	References
47	Supercapacitors based on carbons with tuned porosity derived from paper pulp mill sludge biowaste	[71]

Sustainable Plastic Management

Pyrolysis and co-pyrolysis of plastic waste is one of the environmentally friendly ways for transforming plastic waste into value-added products. Research evidences revealed that co-pyrolysis of biomass and plastic wastes exhibited high production of bio-oil and low production biochar [2-4]. Plastic bottles into engineered biochar for post-combustion CO_2 capture, successfully mitigating two critical environmental issues of plastic pollution and climate change simultaneously, and this approach was further identified as a closed carbon loop from the life-cycle perspective, which is beneficial to achieve carbon neutrality by 2050 and sustainable plastic management. The environmental consequences of plastics are not completely revealed [51]. However, there are many noticeable long-term impacts on lives on earth. Hence, sustainable upcycling of plastic waste is a vital necessity to slow down the rate of plastic incorporation to environment. Investigations and applications of modern approaches will be provided enormous advantages to overcome environmental threats. Biochar production could be developed as a very sustainable solution to mitigate the plastic waste generation around the world [52,59]. As discussed above, biochar can be produced by both pyrolysis and co-pyrolysis of plastic wastes. Pyrolysis serves as a viable route for the upcycling of plastics with an advantage of energy recovery along with its simplicity for the production of fuels and gases [56]. Moreover, the conversion of plastic waste to value added products like carbon nanotubes and other carbon nanomaterials (e porous carbon nanosheets) which can be used in CO_2 adsorption and other industrial applications provide useful insights in circular economy.

Environmental Impact for Utilization of MSW

The economic analysis of MSW management revealed that with an increase in the production of MSW in the last decade, conventional methods such as landfilling and integrated waste conversion became very expensive due to less availability of space [70]. So, the utilization of MSW for the production of bio-materials such as bioplastics, biofertilizers is a sustainable, economic and environment-friendly solution [60]. While in another study, the MSW was supplemented with basal medium components such as fruit by-products and glucose which gave good fermentation yield with the solvent extraction [72]. Further, there is a need to develop some technologies that can segregate the waste for its utmost utilization for biobased products formation. The organic fraction of MSW containing the rich amount of nutrients can be used for the production of bioproducts that helps attain the sustainability and circular bioeconomy [50,61,71]. Waste treatment and disposal includes recycling, composting, anaerobic digestion, incineration, landfilling, open dumping, and dumping in marine areas. The impact of solid waste on health may vary depending on numerous factors such as the nature of waste management practices, characteristics, and habits of the exposed population, duration of exposure, prevention, and mitigation interventions [51,62,63]. An investigation of the relationship between solid waste and human health begins with hazard identification and exposure assessment [28,64,65]. Other practices, such as waste disposal in landfills or dumpsites, can also affect groundwater through the leaking of leachate, the consequent exposure would be represented by the ingestion of water contaminated with toxic or carcinogenic compounds. epidemiological studies on health effects associated with management of solid waste except for dumpsites and open burning areas [52,59,66,67]. Some investigation shows health effects focusing on people living near landfills and incinerators. In many cases, the authors suggested that MSW management practices can pose some adverse health effects for the population residing nearby, although the current evidence often lacked statistical power, highlighting the need for further investigations [53-55]. It has to be highlighted that solid waste legislation influences the technological level and emission limits associated with solid waste management plants, such as landfills and incinerators. Definitely, in many European countries, modern technology has been reducing noxious emissions, and measurable health impacts have become smaller [56,57]. At the same time, it has to be considered that the so-called emerging contaminants (ECs) are not commonly monitored in the environment, but they have the potential to enter the environment and cause known or suspected adverse health effects. Many new chemicals are constantly approved for commercial use; for example, over 40,000 chemicals are actively being manufactured, processed, and imported in the United States, but the health effects of few of them have been monitored in the population [58,73]. Such substances can easily reach the solid waste phase, leading to underestimated adverse health outcomes. Besides, countries with weak environmental legislations can be affected by additional risks.

Discussion

The fertilizing potential of MSW compost has been demonstrated by its high nutrient concentrations, particularly N, K, P, Ca, and Mg. The percentage of inert impurities in the compost with a size larger than 2 mm, such as plastic or glass, was seen to be excessively high, exceeding, in some cases, the legal limit [74,75]. The source of such pollution lies in the composting inputs wherein the organic fraction of MSW showed high percentages of improper materials such as plastic and glasses. The composting process can be carried out in the dwellings of the community to fertilize the soil; this is a good way in which people can reduce their organic waste. Composting can be undertaken on a small community or residential scale with material recovered from the landfill, using a part for fertilizer and other treatment of the soil surrounding the landfill to reduce the leachate [68,69,76,77]. This lowers the barrier to adoption for these processes in the community. Non-organic and dry waste can be incinerated after the segregation process and combusted to produce energy. During waste decomposition, engineering landfill systems produce methane that can be captured, contained, and combusted to generate energy [78-80]. All of these options are focused on reducing the environmental impacts of waste generation and waste management, thereby strengthening the economic value of waste. Innovative treatment technologies such as gasification and pyrolysis must be implemented [81,82]. Waste is currently openly burned at PNG landfill facilities and within the community. These uncontrolled combustion activities create a significant environmental burden with airborne pollution causing adverse health impacts to the community [83,84]. Collection and transportation are usually the major parts of waste management costs, much more than landfill costs. Trucks, bins, and workers are an essential part of the process and represent a constant expense; the former requires capital expense and maintenance, and the latter a monthly wage [85–87]. A truck needs to be easy to load and unload, and should have an appropriate capacity for the amount of waste to be collected. It also needs to be able to adapt to the geography of the covered area so that the maintenance costs remain low. The government has sought to prohibit the import and use of plastic bags in order to prevent the production and accumulation of plastic waste [88-90]. By collecting and segregating waste from several areas which represent different socioeconomic groups, the team was able to determine the household generation rate, the composition, and the density of waste disposed to landfill. This also acts to build local knowledge and skills in decision-making, developing policies, and strategies for waste minimization. Gampaha Municipal Council of Sri Lanka had launched a pilot project on home composting, and the result shows that the waste generated was reduced by 69% [91-93]. Successful practices in several European countries suggest that source-separated composting presents many advantages over mechanical-separated composting [94]. This may partially be ascribed to the fact that source separation of organic waste can prevent contact with heavy metal-bearing items, resulting in the production of high-quality compost. Mixed collection solid waste normally contains significantly higher concentrations of heavy metals, which could affect the marketing of composting products [95,96]. Moreover, source separation of organic waste can minimize waste pre-treatment operations, leading to lower bio-aerosol and malodor generation during composting. Standards must be set for end-product quality control and highly recommended to control both marketing and environmental risks [97]. the characterization of landfill leachate was performed in Asia, Africa, and Latin America, and it was found that three heavy metals, viz. Ni, Cr, and Zn, were significantly present at dumpsites [98]. It was found that the concentrations of pollutants from sites are influenced mainly by local conditions, consumption patterns, and waste management habits of individuals [99]. Thus, properly engineered landfill sites effectively reduce the risk associated with these pollutants.

Conclusion

MSW can be considered as a cheap raw material for the production of high-value products as it reduces the operational cost and helps in environmental sustainability as well. Hence, based on this study, it can be deduced that MSW should be segregated into major fractions for the development of high-value products and should be considered as a valuable resource, which can be further explored to develop many other novel products [100,101]. For reuse and recycling in LC, the most significant opportunity is the adoption of composting processes on a residential, community, and industrial scale, considering the composition is mainly organics [102]. On the residential and community level, vermicomposting is suggested as a sustainable, economically viable, and easy method to stabilize organic waste without any adverse effects to the environment or human health [103]. Fly ash is recommended for use in building materials such as hybrid cement. Disposal is inevitable in the waste management process [104,105]. The Fukuoka method offers a promising solution for the remedia-tion of the second seventh landfill (SSL) by capturing leachate and methane recovery [106]. This approach has proven successful in emerging nations with similar landfills due to its simplicity and low cost, which lowers the barrier to its implementation.

Contribution

AKM, BP designed and wrote the manuscript. SNP, BP, CRS analyzed the data and finalized the manuscript.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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