Sustainable Conversion of Solid Waste into Energy: Review

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Abstract— **Critical issue of solid waste management is spreading all over the world. As urbanization is increasing with rise in population, the amount of solid waste generation has increased tremendously. Moreover inappropriate disposal of waste has caused extreme environmental and human health issues. Also it has started depletion of resources. Hence, correct organization of methods for treatment of solid waste is essential to mitigate these problems. Further, there is a need for an efficient waste management system. In this context one excellent way to solve this issue is conversion of solid waste to valuable form such as energy. It can also reduce dependence on conventional fuel sources for demand of energy. This paper reviews the current state of solid waste management practices and the potential for the production of energy from solid waste.**

Index Terms— **Solid waste management, environmental and health hazards, resource depletion, production of energy.**

I. Introduction

Amount of solid waste is steadily growing in developing countries such as India due to the continuous growth of population which leads to increased industrialization and urbanization. The tremendous advancements in technology and economics has risen the material production and consumption that resulted in increased amounts of trash. Thus Municipal solid waste (MSW) management is currently dealing with growing complexity and heterogeneity caused by growing population. The objective of managing solid wastes is now to analyze prospective technologies and diverse applications for an environmental friendly way. In this context Waste-to-energy (WtE) is a pivotal big-movement for managing municipal solid waste (MSW) sustainably [1], as municipal solid waste is considered as a significant renewable energy resource [2,3]. As improper disposal and mismanagement of municipal solid waste (MSW) not only has pessimistic environmental effects but also causes the hazard to public health and ascent some other socio-economic issues that are couturier discussions. Therefore, it is essential to desperately intensify the whole system starting from waste collection, segregation, and finally safe disposal. One novel technology emerged in these years in both developed and developing countries like India is Waste to Energy(WtE) incineration [4]. WtE has become most promising technology for MSW management. Due to its prospective to produce biofuels and platform chemicals from the organic part of MSW, such as food wastes. Though waste biorefnery has gained a lot of attention in recent years but, till date it is facing criticism, social disapproval and fear from population as it possibly increases the production of green house gases and harmful compounds during combustion[7, 8]. The latent results of socialization a new "bioeconomy" by enormous importance of material recycling is the scope of energy recovery. WtE incineration is presently a convenient option but the solitary way to warrant that worldwide waste disposal is irreversibly decrease is for the circular economy to follow in the period of time [9]. Because of this, the extent of assessing suitable environmental friendly methodologies in sustainable solid waste management already includes more than just keep in account of environmental quality; it also includes effectuate the substantially more aspiring sustainability targets of energy and recycle of materials. As the bioeconomy rises up, it is clear that MSW management must hold a panoramic explanation of WtE technologies that can forms fuel derived from wastes and generate energy and electricity from it. This is possible by the present circular economy program of WtE. It will be more critical than ever to have this new discussion about the bio-economy for sustainable MSW management in order to retrieve resources that go on the far side energy retrieval and can influence conventional primary material sources. Such a epitome shift support government authority and the pertinent aspect to look for WtE choices that are more socially accepted and to grasp MSW management in the future that has the most green potential.

The conservation of bio-diverseness and natural ecosystems, developed closed loop material recycling, and increased approach to renewable energy sources are all possible outcomes of successfully enforce more sustainable MSW management. This piece desire to subjectively measure the welfare and extent of both new waste biorefinery technologies and conventional thermal WtE technologies in this new bioecological treatment, where their updated roles on energy and material recycling are explored. This review will provide researchers, implementing authorities, engineers and policy makers a comprehensive study of sustainable methods of treating municipal solid watses and its conversion to energy by WtE technology.

II. Sustainable Municipal Solid Waste Management

Waste management as a public service started in 1751, it included all policies and methods starting from collection from point of generation to handling and then disposal of wastes[10]. Municipal solid waste management started initially with aim to provide proper sanitation to people. However, in past decades as the amount of waste has increased drastically, current task is the practice of either recycling or quickly removing it by burying and even mining in urban areas[11]. The current aim of Municipal solid waste management is the conservation of resources and environmental protection. It orbit around the conception of "sustainability," and decreasing potential environmental loads for future generations [12]. The waste management organization involves approaches based on their practicality in terms of sustainability when procedures of waste management techniques need to be designed worldwide. Most widely used techniques involves careful disposal of wastes on controlled sites termed as "sanitary landfilling". It includes leachate treatment and biogas recovery. [13] But it often does not results in constructive reuse of recyclables from landfill, in fact it increases wastefulness and do not follows principle of closed-loop system of reuse and recycling. Moreover landfill leachate comprise of huge amount of concentrated compounds that pollutes the nearby ground water sources and surfaces. It causes issue of bad odour in near vicinity and contamination of land. Moreover availability of landfill sites and cost of these services in populated cities has also become a big concern to government authorities and general public over time [14]. Thus there is a big demand of thinking of more efficient methods to reduce trash and recycling of solid wastes by municipal treatment has arisen globally to counterbalance increased burden of depletion of land. This problem has often entered the political sphere in numerous places, where garbage recycling is advocated. This has also give authorities to give focus on principles of circular economy and for long-term viability for greater dissemination of renewable energy and less reliance on imports from foreign resources [15–17]. The first step in doing this is to implement an appropriate waste separation classification system and use of pertinent environmental technology.

Generally referred to as trash or rubbish by the general public, MSW is a broad term for bulk wastes produced by commercial, indu strial, and residential activities. There are various approaches to classify the data [18], with Table 1 offering a generic approach. Industrial trash, medical waste, agricultural waste, and sewage sludge are frequently excluded from the definition of MSW. Different nations generate MSW at different rates per capital.

Briefly put, there are two possible explanations for this phenomenon: (1) locations (typically in developed nations) with appropriate waste reduction policies have set up efficient waste recycling systems that can prevent recyclables like food waste, yard waste, metals, packaging materials, and plastic bottles from entering the waste stream [19]; and (2) inconsistent definitions of MSW used in various waste management policies can also cause significant deviations.

In fact, the EU has also come under fire for its ambiguous definitions of MSW [20], which can lead to internal market fragmentation and a shift in emphasis away from important environmental technologies and policies due to definitional inconsistencies and statistical uncertainty. For a long time, landflling has been the least desirable alternative.

Waste-to-energy (WtE) technologies such as pyrolysis, gasification, incineration, and biomethanation can convert MSW, as an appropriate source of renewable energy, into useful energy (electricity and heat) in safe and eco-friendly ways. This review aims at describing the challenges of MSW management, summarizing the health significance of MSW management, explaining the opportunities and requirements of energy recovery from MSW through WtE technologies, explaining several WtE technologies in detail, discussing the current status of WtE technologies in India.

Municipal solid waste (MSW) can indeed be considered a sustainable resource for energy production through various waste-to-energy (WTE) technologies. Instead of disposing of MSW in landfills, which can lead to environmental issues like methane emissions and land pollution, converting it into energy can offer several benefits:

Renewable Energy Source: MSW is a renewable energy source as it continuously generated by cities and towns. By harnessing this waste for energy production, we reduce dependence on fossil fuels and decrease greenhouse gas emissions.

Waste Reduction: Waste-to-energy facilities help in reducing the volume of waste sent to landfills, extending their lifespan, and alleviating the environmental impact associated with waste disposal.

Energy Generation: WTE technologies can produce different forms of energy, including electricity, heat, and even biofuels. These can be used to power homes, businesses, and industries, contributing to the local energy supply.

Mitigating Greenhouse Gas Emissions: Waste that decomposes in landfills produces methane, a potent greenhouse gas. By converting MSW into energy, we prevent methane emissions and reduce the overall carbon footprint of waste management.

Resource Recovery: WTE processes often involve recovering valuable materials such as metals from the waste before energy production, contributing to resource conservation and reducing the need for raw material extraction. There are several waste-to-energy technologies employed for energy production.

Incineration: MSW is burned at high temperatures to generate heat, which is then used to produce steam and drive turbines to generate electricity.

Anaerobic Digestion: This process involves breaking down organic waste in the absence of oxygen, producing biogas (a mixture of methane and carbon dioxide), which can be used for electricity or heat generation.

Gasification: Waste is heated in a low-oxygen environment, converting it into synthetic gas (syngas) that can be used to produce electricity or biofuels.

Pyrolysis: MSW is heated in the absence of oxygen, leading to the production of liquid fuels, gases, and char.

III. Advantages of Waste-to-Energy

Waste Reduction: WtE facilities can significantly reduce the volume of waste going to landfills, which helps in alleviating landfill space shortages.

Energy Generation: WtE generates electricity and heat, which can be used to power homes, businesses, and industries, thereby reducing the reliance on fossil fuels.

Greenhouse Gas Emissions Reduction: While WtE does release carbon dioxide (CO_2), it can be more environmentally friendly compared to landfilling, as it captures methane emissions, a potent greenhouse gas.

Resource Recovery: The process allows for the recovery of valuable metals and other materials from waste, reducing the need for mining and extraction.

Base Load Power Generation: WtE plants can provide a stable source of electricity, which is especially valuable when intermittent renewable energy sources like wind and solar are integrated into the grid.

IV. Disadvantages of Waste-to-Energy

Environmental Concerns: Some WtE technologies can produce air emissions and ash, which may contain pollutants. Advanced pollution control technologies are needed to address these issues.

High Initial Costs: Establishing WtE facilities can be expensive, which may pose a financial barrier for some regions.

Public Perception: Waste incineration has faced opposition from some communities due to concerns about air quality and health effects.

Limited Waste Types: Not all types of waste are suitable for WtE, and the composition of the waste stream can affect the efficiency of the process.

Competing with Recycling: Critics argue that WtE might discourage recycling efforts, as it could incentivize continued waste generation.

V. Current Trends and Innovations

Advanced Technologies: Ongoing research and development focus on improving the efficiency of WtE processes and reducing emissions. Gasification and pyrolysis are emerging as alternative technologies to traditional incineration.

Circular Economy Integration: Many regions are exploring ways to integrate WtE into a circular economy model, where waste is minimized, materials are recycled, and the remainder is used for energy production.

Waste Sorting and Pre-treatment: Advanced waste sorting and pre-treatment technologies can enhance the quality of feedstock for WtE facilities, improving efficiency and reducing emissions.

Localized WtE: Smaller-scale WtE facilities are being developed to serve local communities and reduce transportation costs associated with waste disposal.

Energy Efficiency: Combined Heat and Power (CHP) systems are being employed in WtE facilities to maximize energy generation and use.

Carbon Capture and Utilization (CCU): Some WtE plants are exploring the integration of CCU technologies to capture and utilize CO2 emissions.

VI. Conclusion

While these technologies offer significant environmental benefits, there are challenges to consider, such as the initial investment costs, potential air emissions from incineration, and ensuring proper waste separation to avoid harmful pollutants in the energy production process. It's essential to have effective waste management policies and public awareness programs in place to promote recycling and waste reduction, complemented by the sustainable use of waste for energy production.

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