Harnessing Waste for Energy: Solutions to Industrial Waste Management in Madhya Pradesh

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Abstract: ***Madhya Pradesh (MP) is experiencing significant waste management challenges due to rapid urbanization and industrial expansion, resulting in increasing volumes of municipal and industrial waste. The accumulation of waste is straining existing landfill capacities, posing environmental hazards, and creating a need for sustainable waste management solutions. This study investigates the potential of Waste - to - Energy (WtE) technologies as a means to address these challenges by converting waste into usable energy. Data was collected through surveys conducted with industries in the Pithampur area and supplemented by secondary data from government reports and relevant literature. The study assesses the suitability of WtE technologies, such as incineration, gasification, and biomethanation, for processing municipal solid waste (MSW), industrial waste, and organic residues. The analysis reveals that despite MP's significant waste generation, the adoption of WtE technologies is hindered by barriers including poor waste segregation, high implementation costs, and insufficient policy incentives. However, the study estimates that the state has a substantial energy generation potential of 516 MW from WtE technologies, alongside 2488 tons/day of Bio - CNG production capacity. The novelty of this research lies in its focus on MP's industrial waste landscape, providing a region - specific assessment of WtE adoption and emphasizing the need for targeted policy frameworks and technological advancements. The findings of this study not only highlight the untapped energy potential within the state's waste streams but also offer critical insights for policymakers and industry leaders. The research provides a roadmap for integrating WtE technologies into the state's waste management infrastructure, promoting sustainability, reducing landfill reliance, and contributing to the state's renewable energy goals.***

Keywords: Waste - to - Energy, Madhya Pradesh, industrial waste, renewable energy, waste management

1. Introduction

Waste management is a pressing global issue, with rapid urbanization, industrial growth, and increased consumption patterns leading to an unprecedented surge in waste generation. Improper disposal of waste can have severe environmental and public health consequences, including air and water pollution, land degradation, and greenhouse gas emissions (Abubakar et al., 2022; Siddiqua et al., 2022). These challenges are further compounded by the rising global demand for energy. Waste - to - energy (WtE) technologies present an innovative solution that addresses both waste disposal and energy generation (Tsui et al., 2019; AlQattan et al., 2018). By converting waste into valuable energy resources like electricity or heat, WtE technologies offer a sustainable alternative to traditional waste management methods such as landfilling, which often exacerbate environmental problems (Kothari et al., 2010; Kumar & Samadder 2017).

Countries with advanced waste management systems have successfully integrated WtE technologies into their frameworks, reducing their dependence on landfills and simultaneously contributing to energy security (Pires et al., 2011; Batista et al., 2021). The waste hierarchy model, which prioritizes prevention, reuse, and recycling over energy recovery and landfilling, places WtE technologies in the "energy recovery" tier (Awino et al., 2024; Hoang & Fogarassy; 2020; Egüez; 2021). This approach ensures that energy is recovered from waste that cannot be recycled, providing a dual benefit of reducing landfill use and generating energy. Nations like Sweden, Japan, and Germany have set global standards for WtE technology adoption. Sweden, for instance, incinerates approximately 50% of its municipal solid waste (MSW) while sending less than 1% to landfills (Istrate et al., 2020; Bruno et al., 2021). Japan, which has one of the world's most developed WtE systems, processes 78% of its waste in over 1, 000 incineration plants, many of which have advanced flue gas cleaning systems to control harmful emissions (Khan et al., 2022; Cui et al., 2020). These countries' success stems from strict environmental regulations, high landfill taxes, and government incentives that encourage investment in WtE infrastructure.

In contrast, countries like the United States still rely heavily on landfills due to lower regulatory pressures and the availability of land, with only 13% of its MSW being processed through WtE plants (Maturi et al., 2022; Alamu et al., 2021). The difference in adoption rates between regions underscores the importance of regulatory frameworks, financial incentives, and public perception in the successful implementation of WtE technologies. The environmental and economic benefits of WtE are clear, yet the barriers to adoption, particularly in developing economies, are substantial.

India, with its rapidly expanding urban population and industrial base, faces a significant waste management challenge. Urbanization in India has grown dramatically, with the urban population rising from 27.8% in 2001 to 31.6% in 2011, and projections suggesting that 50% of the population will reside in urban areas by 2021 (Kumar et al., 2020; Dutta et al., 2020; Khan et al., 2022). While the expansion of services such as transportation, electricity, and water has kept pace with this growth, municipal solid waste (MSW) management has lagged behind. The consequences are evident in the form of open garbage dumps, unmanaged waste, and growing public health risks in many Indian cities. Over the last few years, the volume of waste generated in India has sharply increased. By January 2020, the 84, 475 wards across India collectively generated 147, 613 metric tons (MT) of solid waste daily (Saifi & Jha; 2023). This figure continued to rise, with urban India producing 276, 342 tons per day (TPD) of waste by 2021. According to a Planning Commission study on the "Task Force on Waste to Energy, " India has the potential to generate 1.68 GW of energy from its waste. With projections estimating that waste generation will increase to 450, 132 tons per day by 2031 and 1, 195, 000 tons by 2050, it is imperative that the country finds sustainable waste management solutions (Raut et al., 2023).

In the context of Madhya Pradesh (MP), one of India's largest and fastest - growing industrial states, these challenges are especially relevant. The state is experiencing significant industrial growth, leading to increasing volumes of both industrial and municipal waste (Ghosh., 2020; Mohanty et al., 2022; Lal Patel et al., 2011). The pressure on waste management infrastructure is immense, and without sustainable solutions, this waste could pose serious environmental and public health threats. MP's current waste management practices rely heavily on landfills, which not only contribute to land degradation and pollution but also represent a missed opportunity to convert waste into a valuable energy resource (Vishwakarma et al., 2012; Parihar et al., 2017).

Despite these barriers, WtE technologies offer a promising pathway for India to address both its waste management and energy security challenges. The novelty of this research lies in its focus on how different WtE technologies—such as incineration, gasification, and anaerobic digestion—can be effectively implemented in India's unique industrial and urban context. This study aims to develop a framework that bridges the gap between technological capabilities and the financial, regulatory, and infrastructural requirements necessary for successful WtE adoption. By integrating WtE facilities with existing power plants, industrial zones, and municipal waste systems, India can unlock the dual benefits of reducing landfill dependency while generating clean energy.

The objectives of this research are to assess the potential of various WtE technologies in India, particularly in urban and industrial regions, and to identify the economic and policy strategies needed to overcome barriers to adoption. Through a comprehensive analysis of existing WtE projects and best practices from around the world, this research aims to provide a roadmap for scaling up WtE technologies in India, contributing to both sustainable development and energy security. Overall, waste - to - energy technologies present a significant opportunity for addressing India's growing waste management and energy needs. However, their successful implementation will require overcoming key challenges related to waste segregation, financial investment, public perception, and policy support. By adopting a holistic approach that integrates technological innovation, regulatory reforms, and community engagement, India can harness the full potential of WtE technologies and set a global precedent for sustainable waste management.

2. Study Area: Madhya Pradesh (MP)

MP, located in central India, is the second largest state by area, covering 308, 245 square kilometers, and ranks fifth in terms of population, with an estimated 8.77 crore residents. Bhopal serves as the state capital, while Indore is the largest city and a rapidly expanding industrial hub. Other significant urban centers include Gwalior, Jabalpur, Ujjain, Dewas, Sagar, and Rewa.

2.1 Geography and Climate

MP is characterized by a diverse topography, including plateaus, river valleys, hills, and forests. The Narmada and Tapti rivers flow through the state, significantly influencing its agricultural productivity. The state experiences a subtropical climate, marked by hot summers, a monsoon season, and mild winters (Ahirwar et al., 2021). Average annual rainfall is around 1370 mm, but it varies significantly across the state, with southeastern districts receiving as much as 2150 mm, while the western and northwestern regions receive less than 1000 mm (Ganaie et al., 2023). The seasonal climate includes hot, dry summers, monsoon rains from July to September, and cooler winters, with regional variations based on topography.

2.2 Industrial and Economic Profile

MP is a key industrial region in India, benefitting from significant infrastructural investments over the past decade. This development includes the establishment of six Inland Container Depots (ICDs) and four major investment corridors to promote industrial growth: Bhopal - Indore, Bhopal - Bina, Jabalpur - Katni - Satna - Singrauli, and Morena - Gwalior - Shivpuri - Guna. Indore, in particular, has emerged as an industrial powerhouse with a diverse range of sectors such as agro - processing, chemical manufacturing, and textiles. Pithampur, near Indore, is home to India's first green - field SEZ, while the state has several other sector - specific industrial parks.

MP's agricultural sector is also a major contributor to its economy. The state leads the country in the production of soybean, pulses, and gram, and is a major producer of wheat, maize, and fruits such as bananas, oranges, and guavas. The region is known for its organic farming, contributing more than 40% of India's organic produce (Jonnala et al., 2020).

2.3 Waste Management and Energy Potential

MP generates approximately 650 metric tons per day (MTPD) of wet waste and 465 MTPD of dry waste, presenting significant challenges and opportunities for waste management (Saifi & Jha., 2023). With its growing industrial sector, the region has a substantial potential for Waste - to - Energy (WtE) technologies. Implementing WtE technologies could address the state's waste management issues, reduce landfill dependency, and contribute to energy security, particularly in industrial areas like Indore. Modern WtE plants, utilizing technologies such as anaerobic digestion, pyrolysis, and incineration, offer a viable solution for converting industrial and municipal waste into clean energy (Gupta et al., 2022). Figure 1 depicts the number of industries in various cities across MP, highlighting the extent of waste generation and consequently the opportunity for WtE generation.

Indore's industrial waste streams include agro - industrial residues, chemical by - products, and textile effluents. The adoption of WtE technologies in this region could significantly reduce environmental pollution, particularly for industries generating hazardous wastes, such as chemical and textile production. However, there are several barriers to widespread adoption, including inconsistent government policies, financial constraints, and the need for advanced waste segregation practices.

MP's combination of robust infrastructure, diverse industrial base, and proactive government policies make it a promising candidate for sustainable development initiatives, particularly in the area of Waste - to - Energy conversion. The integration of WtE technologies could contribute to reducing the state's carbon footprint, improving waste management, and enhancing energy security.

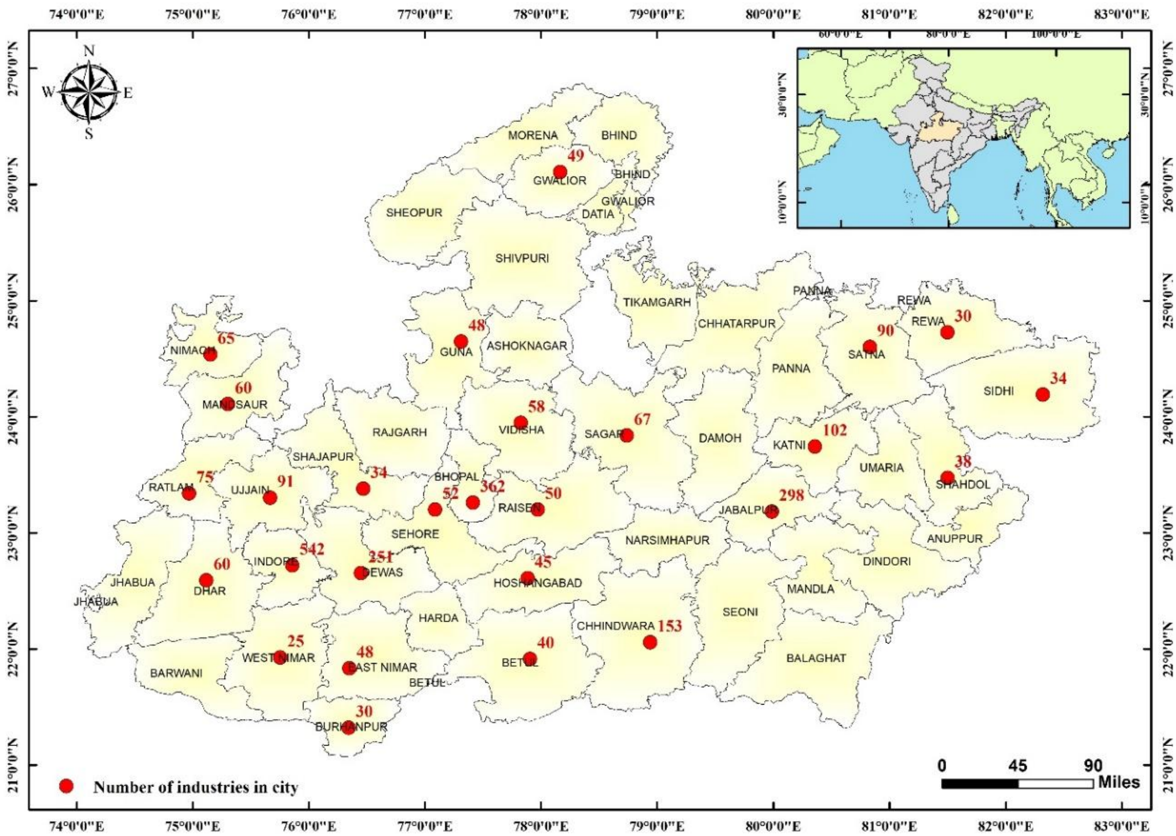

Figure 1: Depicts the location of cities in MP, and the number of industries in various cities across MP

3. Data and Methodology

3.1 Data Collection

This study draws from both primary and secondary data sources to assess the potential for waste - to - energy (WtE) technologies in Indore's industrial sector. Primary data was collected through surveys conducted with industries in the Pithampur area, including Shivani Detergent Pvt. Ltd., Adoit Industries, and Signet Industries. These surveys focused on waste generation volumes, disposal methods, and the current use of WtE technologies. Field visits to waste management sites in Indore provided further insight into the operational challenges and current waste handling practices.

Secondary data was obtained from government reports, particularly from the Madhya Pradesh Pollution Control Board, which provided essential figures on waste generation and the energy potential of various WtE technologies. Additionally, a literature review of WtE technologies like gasification, pyrolysis, and biomethanation helped contextualize the findings within global best practices.

3.2 Analytical Approach

The study classified waste into categories and analyzed the energy potential of each type using different WtE technologies. Incineration was evaluated for solid waste, gasification for industrial waste, and biomethanation for organic waste from agricultural and cattle farming activities. Energy potential was estimated using known conversion rates and available waste data.

A mixed - methods approach, integrating qualitative insights from industry surveys and quantitative data analysis, was applied to assess the feasibility, efficiency, and barriers to WtE technology adoption. This methodology provides a comprehensive framework to guide future policy and investment decisions in waste management and energy generation for the industrial and urban sectors of MP.

4. Results and Discussions

4.1 Key Technologies for Waste - to - Energy Conversion

MP, with its diverse industrial and agricultural sectors, presents a significant opportunity for the implementation of Waste - to - Energy (WtE) technologies. The state generates substantial amounts of waste from agro - industrial operations, solid waste, and cattle farming, all of which can be harnessed through different WtE technologies. By effectively converting this waste into usable energy, MP could reduce its reliance on landfills, mitigate environmental pollution, and enhance its energy security. Figure 2 summarises principle techniques that can be employed for WtE conversion, and Table 1 provides overview of Waste - to - Energy (WtE) Technologies for different waste types in MP.

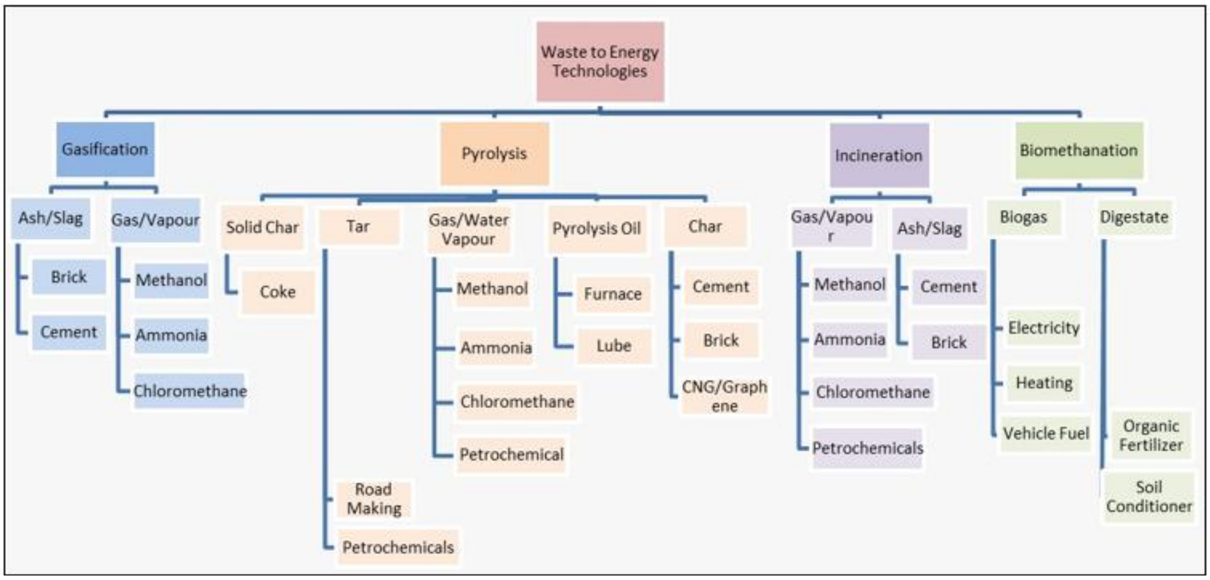

Figure 2: Illustrates the primary technologies used for Waste - to - Energy (WtE) conversion. The chart highlights four main processes: Gasification, Pyrolysis, Incineration, and Biomethanation.

Gasification presents promising WtE technology for MP, especially in industrial sectors such as agro - processing and paper manufacturing. The paper industry in the state, which produces both liquid and solid waste, can benefit from gasification by converting these waste streams into syngas (Meena et al., 2024; Khattra et al., 2024). The syngas produced can then be used for electricity generation or as a feedstock in chemical industries. Given the relatively lower emissions from gasification compared to incineration, this technology is highly suited to MP’s regulatory landscape, where environmental concerns are growing alongside industrial expansion. By integrating gasification plants with industries that generate large amounts of biomass and RDF (refuse - derived fuel), the state could tap into an energy source that is both clean and reliable.

Pyrolysis is another important technology for MP, particularly for the treatment of plastic and other non - biodegradable waste, which is a growing concern in urban areas. The state’s urban solid waste, which amounts to 6, 773 tons per day, contains significant amounts of plastics and other materials that could be more effectively managed through pyrolysis. By converting plastics and organic materials into bio - oil, syngas, and biochar, pyrolysis could provide a solution that minimizes landfill use and creates valuable by - products (Kataki et al., 2022; Sharma et al., 2021; Malav et al., 2020). Biochar, in particular, holds potential in MP’s agricultural regions, where it can be used as a soil amendment, improving soil health while sequestering carbon. This aligns with the state's dual goals of enhancing agricultural productivity and addressing environmental challenges related to waste.

Incineration is particularly relevant for the management of solid waste in urban centers like Indore, where significant volumes of waste are generated daily. The city alone produces around 689, 000 tons per annum (TPA) of solid waste. Incineration can reduce the volume of this waste, diverting it from landfills and generating electricity in the process. However, as with other regions in India, one of the challenges facing MP is the potential environmental impact of incineration, particularly emissions. To mitigate these concerns, advanced flue gas treatment systems must be installed to ensure that harmful pollutants are captured before being released into the environment (Cui et al., 2020; Khan et al., 2022). This will allow cities like Indore and Bhopal to sustainably manage their municipal waste while contributing to the state’s energy grid.

Another useful WtE technique is Biomethanation, which offers great potential in MP, particularly given the state's high levels of organic waste generated from agriculture, food processing, and animal husbandry. With agriculture playing a vital role in the state's economy, the availability of waste streams like crop residues and animal manure makes biomethanation an ideal solution. For instance, the state produces a large amount of cattle manure, as highlighted by the fact that cattle farms account for 66% of total waste generation in the region. By utilizing biomethanation, this organic waste can be converted into biogas. The generated biogas can be used for local electricity production or upgraded into BioCNG for use in transportation. As an example, converting cattle dung into biogas has been estimated to produce around 1, 649 tons per day (TPD) of BioCNG in the state, contributing significantly to energy needs in both rural and urban areas (Zavarkó et al., 2021; Dar et al., 2021).

Each of these technologies can be strategically applied to the specific waste streams found in MP. For example, gasification and incineration are well - suited to handle the large volumes of solid waste and agro - industrial residues, while biomethanation offers a sustainable solution for the abundant organic waste produced by cattle farms and food processing industries. The success of these technologies in the state will depend on careful planning and investment in infrastructure, as well as government policies that incentivize their adoption. Overall, MP stands to benefit immensely from a diversified approach to Waste - to - Energy conversion. By implementing technologies like gasification, pyrolysis, incineration, and biomethanation the state can turn its waste management challenges into opportunities for sustainable energy production. With the vast availability of waste across agricultural, industrial, and municipal sectors, these technologies can not only reduce environmental pollution but also contribute significantly to the state's energy needs.

Table 1: Overview of Waste - to - Energy (WtE) Technologies for Different Waste Types in Madhya Pradesh

Waste Type	WtE Technology	Energy Output	Waste Volume (TPD)	Major Source in MP	By - products	Technology Maturity	Challenges
Organic (Cattle dung, crop residues)	Biomethanation	Biogas, BioCNG	1, 649 (Bio - CNG TPD)	Cattle farms, food processing units	Digestate (used as fertilizer)	Well - established	Requires good waste segregation
Solid Waste	Incineration	Electricity, Heat	6, 773 TPD	Urban centers (Indore, Bhopal)	Fly ash, bottom ash	Well - established	High emissions, needs advanced filtration
Industrial Waste (Paper, Agro - residues)	Gasification	Syngas, Electricity	952 million m³ (liquid)	Paper, agro - industrial sectors	Char, tar, heat energy	Emerging	Capital intensive, requires RDF
Plastic and Non - biodegradable waste	Pyrolysis	Bio - oil, Syngas, Biochar		Urban plastic waste, industrial	Biochar, Bio - oil	Emerging	Requires advanced waste sorting
Food and Vegetable Waste	Biomethanation	Biogas, BioCNG	2 TPD	Food markets, processing industries	Digestate	Well - established	Requires organic waste sorting
Sewage Sludge	Anaerobic Digestion	Biogas, Electricity	923 million m³ (liquid)	Sewage treatment plants (STP)	Sludge, treated water	Well - established	High maintenance of STP required
Distillery Waste	Gasification	Syngas, Electricity	1 million m³ (liquid)	Distilleries and breweries	Tar, heat energy	Emerging	Complex gas clean - up needed
Poultry and Meat Waste	Biomethanation	Biogas, Electricity	462 TPD (solid)	Poultry farms, slaughterhouses	Digestate	Well - established	Handling odor and animal residues
Sugar Press Mud	Biomethanation	Biogas, BioCNG	200 TPD	Sugar industries	Organic manure	Well - established	Seasonal availability of waste

4.2 Waste Management and Energy Potential in Madhya Pradesh (MP)

The current state of waste management in MP, is summarised in Table 2, which delves into the waste generation, treatment, and energy potential in the region, supported by data from key sectors. Figure 3 shows that MP generates a substantial amount of solid waste, approximately 6, 773 tons per day (TPD). Out of this, 5, 480 TPD is collected, with 4, 339 TPD going to landfills. A mere 1, 141 TPD of waste is treated, with only 440 TPD used in WtE processes (MPPCB, 2023). The significant disparity between collected waste and treated waste highlights a vast potential for expanding WtE technologies to reduce the amount of waste being landfilled. Given this gap, there is considerable scope to divert more waste toward energy generation and composting.

MP has implemented a "Cluster Based Integrated Solid Waste Management" (ISWM) framework to improve waste processing and energy generation. According to the Madhya Pradesh Pollution Control Board (MPPCB, 2023), 11 clusters have been formed for this approach, with the central government providing Rs.24 crores to municipal bodies with populations exceeding 1 million for setting up Waste - to - Energy (W2E) plants. The clusters will go through competitive bidding to select contractors for the WtE facilities.

In Indore, eight nearby towns have come together to form the Indore Cluster, processing 1, 040 metric tons of waste per day. This includes a 40 TPD biogas plant and a 1, 000 TPD WtE plant. The electricity generated will be sold to utility companies at Rs.7.04 per unit. Indore is also constructing an 11.5 MW W2E plant. Additionally, the city generates 689, 000 TPA of solid waste and 425 MLD of liquid waste, with an estimated energy potential of 10 MW and a Bio - CNG potential of 49 TPD. This data underlines the city's capability to contribute meaningfully to the region's energy grid, emphasizing the need to leverage these waste streams more efficiently through advanced WtE technologies.

Table 2 provides an overview of the potential for energy and bio - CNG generation from solid and liquid waste in MP across various industries. The solid waste from cattle farms alone accounts for the highest energy potential at 341 MW, with a significant Bio - CNG potential of 1649 tons/day. Solid waste (SW) in urban centers contributes to 44 MW of energy generation potential and 212 tons/day of Bio - CNG.

Industries dealing with fruits and vegetables (both raw and processed) also show a substantial contribution to waste generation but lack significant energy or Bio - CNG conversion potential.

Liquid waste, primarily from the sewage sector, has a considerable presence, with 923 million cubic meters of liquid waste and an energy generation potential of 25 MW. The paper industry and distilleries also add to the liquid waste profile, contributing to Bio - CNG production, with the paper industry alone contributing 139 tons/day of Bio - CNG potential. The table highlights that, in total, MP has a combined solid and liquid waste energy potential of 516 MW, along with a total Bio - CNG potential of 2488 tons/day, indicating significant opportunities for waste - to - energy conversion projects across the state.

The significance of this data lies in the vast untapped potential for generating energy and Bio - CNG from both solid and liquid waste in MP. With 516 MW of energy potential and 2488 tons/day of Bio - CNG production capacity, the state can significantly contribute to its renewable energy portfolio. Cattle farms, which produce the largest amount of solid waste, present an opportunity for large - scale biogas and Bio - CNG production, which could be used to fuel transportation systems or generate electricity for rural areas. Municipal solid waste (MSW) from cities like Indore and Bhopal also offers significant potential for WtE projects, helping reduce the strain on landfills while providing clean energy for urban centers.

The large volumes of liquid waste, particularly from the sewage and paper industries, present additional opportunities for energy recovery and resource utilization. By tapping into the energy potential of liquid waste, the state can reduce environmental hazards posed by untreated effluents, while simultaneously supporting its energy needs. The combined approach to managing both solid and liquid waste through WtE and Bio - CNG projects would not only promote sustainable waste management practices but also drive economic growth by generating energy, creating jobs, and reducing reliance on fossil fuels.

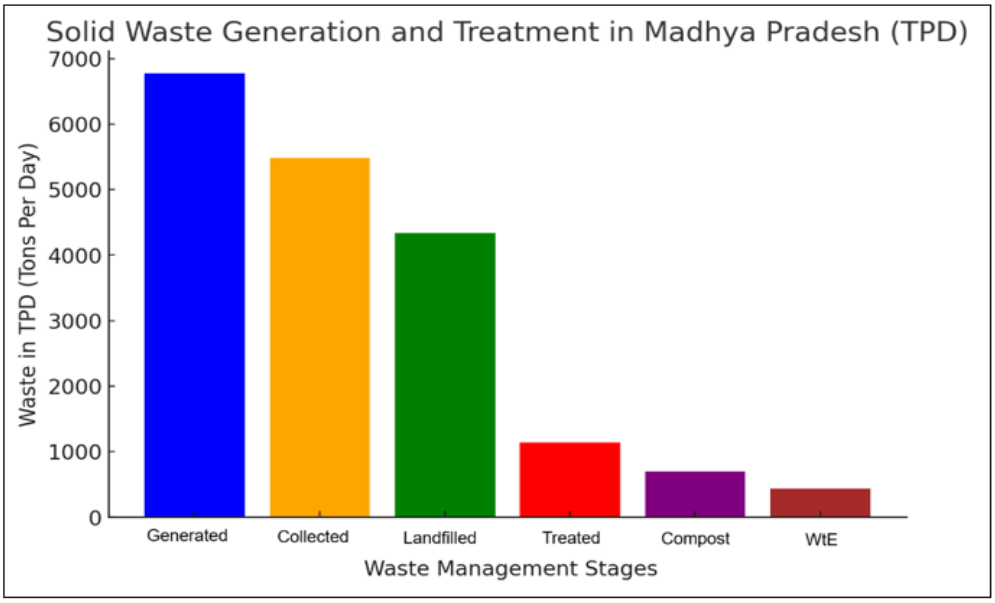

Figure 3: Illustrates the solid waste generation and treatment process in Madhya Pradesh, measured in tons per day (TPD). The chart highlights various stages of waste management, including the amount of waste generated, collected, landfilled, treated, composted, and utilized for Waste - to - Energy (WtE) conversion.

Table 2: Summarizes the production, energy potential, and Bio CNG potential from different industries producing solid and liquid waste (Data Source: MPPCB; 2023)

Type	Industry	Production (Solid: million ton Liquid: million m^3)	Energy Potential (MNW)	Bio CNG Potential (Tons/Day)
Solid Waste	Cattle Farm	40	341	1649
	Sugar	0	5	23
	Poultry	0	4	17
	F&V Raw	2	58	undefined
	F&V Processing	2	0	0
	MSW	3	44	212
	Other	0		
Liquid Waste	Paper	23	29	139
	Sewage	923	25	118
	Distillery	1	7	33
	Meat			
	Slaughter			
	Others	5	4	2488
Total		Solid: 47 Liquid: 952	516	2488

4.3 Waste - to - Energy (WtE) in Madhya Pradesh: Challenges and Opportunities

MP, particularly in its rapidly urbanizing cities like Indore, faces significant challenges in managing growing volumes of municipal and industrial waste. The state's expanding urban centers, coupled with industrial growth, have increased the pressure on existing waste management infrastructure. Waste - to - energy (WtE) technologies, which convert waste into electricity and other forms of energy, provide a potential solution to these dual challenges. However, despite the opportunities, several obstacles continue to impede the widespread implementation of WtE in MP.

The industrial and adjoining areas around Indore, especially at Sanwer Road, exemplify the state's broader industrial growth patterns. While Sanwer Road was initially identified for major industrial development as part of the city's planning efforts in 1991, a lack of infrastructure has hampered the realization of these plans (Rajput., 2021). Many older industrial areas, such as those in Pardesipura and Pologround, have seen their mills shut down, with land converted into residential or commercial zones by the government (Nimoriya et al., 2015). This transition, while helping to meet the city's housing demands, has also resulted in new challenges for waste management. As the population continues to rise and commercial activities expand, waste generation has surged without a corresponding increase in modern waste treatment and recycling capabilities.

In this context, Indore has become a focal point for WtE initiatives. The city has seen rapid population growth over recent decades, with its population increasing from 537, 000 in 1971 to nearly 2 million by 2011. This boom has placed immense pressure on waste management systems. Indore alone produces over 1000 tons of waste daily, with much of this waste currently being sent to landfills (Nimoriya et al., 2015). The relocation of industries from congested areas into designated industrial zones, such as those around Deo - Guradia Road, presents an opportunity to integrate WtE solutions into both municipal and industrial waste management frameworks. This shift would help address the increased waste loads resulting from both urban expansion and industrial activities.

However, the adoption of WtE technologies in MP has been slow, as observed across India. The state generates approximately 6773 tons of waste per day (TPD), yet only 1141 TPD is treated, with 440 TPD currently used for WtE processes. Most waste still ends up in landfills, which pose long - term environmental risks, such as methane emissions and soil contamination. The planned construction of an 11.5 MW WtE plant in Indore represents a significant step forward. This facility, designed to process up to 1000 TPD of waste, will not only reduce the volume of waste sent to landfills but also generate electricity that can be fed into the grid (Parveen et al., 2020). By purchasing this energy at a fixed tariff of Rs.7.04 per unit, utility discoms will contribute to the plant's financial viability, encouraging further investment in WtE technology. Despite these promising developments, several barriers remain. Waste segregation at the source is a critical issue. Poor segregation of wet and dry waste, as well as hazardous materials, significantly reduces the efficiency of WtE plants.

Table 3 shows the result of our survey for four major industries in Pithampur, near Indore, which demonstrates the challenges posed by inconsistent waste management practices. While these industries—Shivani Detergent Pvt. Ltd., Adoit Industries, Signet Industries, and Pratibha Syntex Limited —make efforts to recycle and manage their waste through third - party services, none currently implement comprehensive WtE systems. Instead, they primarily rely on traditional methods such as waste recycling, solar energy use, and disposal through external waste management firms. This lack of in - house WtE solutions reflects the broader issue of waste segregation and feedstock quality in MP.

Furthermore, public perception and concerns about emissions also hinder WtE adoption. Many people are wary of WtE plants, particularly those that rely on incineration, due to fears about harmful pollutants such as dioxins and furans. The failure of past WtE projects in India, often due to poor emissions control and community opposition, continues to affect public trust in such technologies. Addressing these concerns will require not only the implementation of advanced emissions control technologies but also transparent communication with local communities about the environmental and health benefits of WtE systems.

The financial viability of WtE projects is another significant challenge. Establishing and maintaining WtE plants requires substantial capital investment. Without strong government support in the form of subsidies or long - term financial incentives, private investors are reluctant to participate. The operational costs, including advanced flue gas treatment systems and skilled labor, further increase the financial burden. In this regard, the planned WtE projects in Indore may serve as a model for future investments, particularly if the government continues to offer financial incentives to encourage private sector participation.

MP, with its growing industrial base and urban population (Table 4), has a pressing need to adopt WtE technologies to address its waste management challenges. The ongoing efforts in Indore, particularly the development of an 11.5 MW WtE plant, provide a promising model for other cities and regions in the state. However, the success of these initiatives will depend on overcoming key barriers such as poor waste segregation, public resistance, and financial challenges. With proper government support, enhanced public engagement, and a focus on technological innovation, MP can make significant strides in sustainable waste management, turning its waste into a valuable energy resource for the future.

Table 3: Presents survey results from five industries in Pithampur and Indore regarding their waste generation, types of waste, third - party waste disposal services, Waste - to - Energy (WtE) usage, and primary methods of energy generation

Company Name	Waste generated per month	Types of waste generated	Third - party service used for waste disposal	Waste - to - Energy (WtE) used (currently or past)	Primary method used to generate energy
Shivani Detergent Private Ltd., Pithampur, Indore	1800 Ton target laminate – 1800 ton Plastic waste	Spent oil – non hazardous, Vacant Drum = hazardous - 2 ton, Cotton Grees – 1 ton, Sludge - 1 ton	Yes - Hgargo (recycle vacant drum, cotton wastage, laminate)	No	Through STP treated water using in gardening
Adoit Industries (India) Limited, Pithampur, Indore	400 MT	Coolent Oil	Send Oil To Swarn Lubricants Pvt. Ltd, 699 Akun Industrial Area, pithampur (common hazardous waste - treatment storage disposal facility)	No	
Signet Industries Limited, Pithampur, Indore			Ramkey Waste Management Ltd (Recycling).	No	Solar
Pratibha Syntex Limited (Unit 1, 2 and 3), Indore	Non Hazardous is 448 tons per month, and hazardous is 3.36 tons per month	Cotton, fabric, paper, plastic, carton, coal, elastic, iron, wooden, empty containers, used oil, sludge, PVC drums, biomedical waste	Sludge is MPIWMPL, Oil used is Sagarshree Lubricants, PVC Drums are Safal Traders (rest are reused or sold to recyclers)	No, not yet.	Purchased Electricity, Roof Top Solar, biomass boiler
Ariba Foods Private Limited	7 tons per month	Food waste, plastic, chemical treatment (hazardous)	For Food waste= Aaryan Associates, Plastic Waste= recycling, Hazardous= Daga Petrochemicals	No	Purchased only, no method of generation.

Table 4: Shows the population growth of five major cities in Madhya Pradesh (Bhopal, Jabalpur, Gwalior, Sagar, and Indore) from 1971 to 2011

Year	Bhopal Population	Bhopal Growth Rate (%)	Jabalpur Population	Jabalpur Growth Rate (%)	Gwalior Population	Gwalior Growth Rate (%)	Sagar Population	Sagar Growth Rate (%)	Indore Population	Indore Growth Rate (%)
1971	575444	-	575275	-	498122	-	118207	-	537000	-
1981	829927	44.68	782482	36	683299	37.2	163000	37.9	829327	44.68
1991	109000	31.63	1023000	30.7	1002000	46.6	231000	41.7	1109000	31.63
2001	1458416	31.5	1098000	7.3	1053505	5.1	274556	18.9	1626297	41.31
2011	1798218	23.3	1268848	15.6	1102884	4.7	308366	12.3	1960631	20.55

4.4 Policy Framework and Technological Integration

4.4.1 Government Policies and Incentives

The implementation of Waste - to - Energy projects in Madhya Pradesh heavily relies on strong policy support. National policies, such as the Swachh Bharat Mission, promote solid waste management and provide some funding for WtE projects. However, specific state - level policies and incentives are needed to streamline the adoption of WtE technologies in industrial settings. Madhya Pradesh could benefit from targeted incentives such as feed - in tariffs for electricity generated from waste and subsidies for technology adoption. Further, regulatory mandates requiring industries to segregate their waste streams at the source can help ensure better feedstock quality for WtE technologies. This would make gasification, pyrolysis, and biomethanation more efficient and economically viable.

4.4.2 Government Policies and Incentives

Integrating WtE technologies with existing energy and waste management infrastructures in Madhya Pradesh is crucial. A comprehensive approach that links WtE plants to local energy grids, industrial zones, and municipal waste collection systems can create a seamless flow of resources. One potential model for MP is the development of industrial symbiosis systems, where industries share resources like energy, water, and waste products. For example, an agro - industrial plant could supply organic waste for biomethanation, while an adjacent chemical industry uses the generated electricity and heat. This approach would significantly enhance resource efficiency while reducing operational costs for industries.

4.4.3 Government Policies and Incentives

Countries such as Germany, Sweden, and Japan have successfully integrated WtE technologies into their waste management and energy generation systems. Learning from their experiences, MP can adopt best practices like:

- Ensuring stringent emissions control through continuous monitoring systems.
- Developing public - private partnerships (PPP) for large - scale WtE projects.
- Creating awareness campaigns to increase public support and reduce opposition to WtE facilities.

5. Conclusion

This study underscores the vital role of Waste - to - Energy (WtE) technologies in addressing the waste management challenges in Madhya Pradesh, driven by rapid urbanization and industrial growth. The state generates substantial amounts of municipal and industrial waste, which, if not properly managed, can lead to environmental degradation. WtE technologies offer a sustainable solution by converting waste into energy, reducing reliance on landfills, and contributing to the state's renewable energy goals. The analysis reveals that Madhya Pradesh has an energy generation potential of 516 MW and the capacity to produce 2488 tons of Bio - CNG per day from waste. Despite this potential, the study highlights several barriers to WtE adoption, including poor waste segregation, high capital costs, and insufficient policy incentives. Inconsistent waste separation at the source decreases the efficiency of WtE plants, while high operational costs and limited financial incentives deter private investments. Additionally, public awareness of the benefits of WtE technologies remains low, further limiting their acceptance and implementation.

For successful WtE adoption, several actions are necessary. Improving waste segregation practices at the source is crucial to ensuring feedstock quality for WtE plants. Enhanced government policies, such as subsidies, tax breaks, and feed - in tariffs for waste - generated energy, will help attract private sector investments. Furthermore, public education campaigns are needed to raise awareness about the environmental and economic benefits of WtE technologies. Overall, Madhya Pradesh has significant untapped potential for WtE adoption, which could drastically improve waste management while contributing to energy security. This study highlights the need for coordinated efforts from policymakers, industry stakeholders, and communities to overcome existing challenges. By integrating WtE into the state's waste management strategy, Madhya Pradesh can move towards a more sustainable, circular economy that addresses both waste disposal and renewable energy generation.

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