

Managing the municipal solid waste and evaluating the viability and technology for producing electricity at Gazipur City Corporation by using Waste.

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

I hereby declare that this thesis “**Managing the municipal solid waste and evaluating the viability and technology for producing electricity at Gazipur City Corporation by using Waste.**” represents our own work which has been done by the students of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering and has not been previously included in a thesis or dissertation submitted to this or any other I institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

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**Dedicated To
Our Parents**

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LIST OF ABBREVIATIONS

MSW	Municipal Solid Waste
WBS	Work Breakdown Structure
GCC	Gazipur City Corporation
JICA	Japan International Cooperation Agency
CDM	Clean Development Medium
WTE	Waste To Energy
LFGE	Landfill Gas to Energy
ISWM	Integrated Sustainable Waste
LCOE	Levelized Cost of Energy
NPV	Net Present Value
CHP	Combined Heat and Power
AD	Anaerobic Digestion
HHV	Higher Heating Value
SSA	Station Service Allowance
UHL	Uncounted Heat Loss
CF	Capacity Factor
NMOCs	Non-Methane Organic Compounds

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ABSTRACTION

Municipal Solid Waste (MSW) management presents significant challenges for rapidly urbanizing areas like Gazipur City Corporation (GCC), Bangladesh. This thesis explores the potential of Waste-to-Energy (WTE) technologies as sustainable solutions for addressing waste management and energy generation challenges in Gazipur. The study analyzes the composition and characteristics of MSW in the city, evaluates WTE technologies including landfill gas-to-energy (LFGTE) and incineration, and assesses their economic viability and environmental impact.

Using the Landfill Gas Emissions Model (LandGEM), methane emissions were projected, and the potential for energy recovery from LFGTE was determined to be 162 million kWh annually, with a low Levelized Cost of Energy (LCOE) of \$0.0017/kWh. Incineration of MSW, with an average input of 1,004 tons/day, was estimated to generate 41.7 MW/day, providing 365 million kWh annually, albeit with a higher LCOE of \$0.01458/kWh.

The findings suggest that both technologies offer viable pathways for waste management and energy generation, with distinct advantages and limitations. LFGTE is more cost-effective, while incineration yields higher energy output but requires greater capital investment. This research emphasizes adopting an Integrated Sustainable Waste Management (ISWM) approach to combine these technologies for maximum efficiency and environmental sustainability.

Keywords

Municipal Solid Waste (MSW), Waste-to-Energy (WTE), Landfill Gas-to-Energy (LFGTE), Incineration, Gazipur City Corporation (GCC), Energy Recovery, Levelized Cost of Energy (LCOE), Integrated Sustainable Waste Management (ISWM), Methane Emissions, Renewable Energy.

Chapter 1

1.1 Introduction

Electrical energy is crucial for daily activities and industrial operations. Municipal Solid Waste (MSW) presents a significant opportunity as an alternative energy source. Despite the potential for using waste to generate energy, such as through biogas production or other energy technologies, waste in Bangladesh is primarily managed through landfilling. As of 2023, Bangladesh's total power generation capacity stands at 25,491 MW, with the peak power demand reaching 16,000 to 16,500 MW during summer. However, frequent load shedding persists due to several factors, including economic challenges, dependence on imported fuels, poorly planned power plant installations, and inadequate energy infrastructure.

Major cities in Bangladesh, including Dhaka, Chittagong, Khulna, Rajshahi, Barisal, and Sylhet, generate approximately 7,690 tonnes of waste daily. Among them, Gazipur City Corporation stands out, producing around 1,747.12 tonnes of household waste daily, of which only 60% is properly collected. [4]Recyclable waste is often salvaged by informal sectors, such as street children, who sell them to scrap buyers. Improper waste disposal in open areas, roads, and drains poses serious environmental and health risks.[1]

Gazipur, covering 1,770.54 square kilometers, with 273.42 square kilometers of forest and 17.53 square kilometers of rivers, had a population of 5,263,450 as per the 2022 census, resulting in a population density of 2,973 people per square kilometer. In the six major cities of Bangladesh, the average waste generation rate is 0.387 kg per person per day, with variation ranging from 0.325 to 0.485 kg per capita.[5]

This study aims to explore various waste-to-energy technologies, including gasification, anaerobic digestion (AD), incineration, and landfill gas recovery. Each of these technologies offers distinct advantages and limitations. By analyzing their feasibility and cost-effectiveness in the context of Gazipur, the study seeks to identify the most practical and sustainable waste-to-energy solution for the city.

1.2 Problem Statement and /or Proposed Solution(s)

Problem Statement:

Waste management has become a significant challenge in preserving environmental and public health in developing countries like ours. Gazipur City Corporation, one of the major city corporations in Bangladesh, faces severe environmental and health issues due to inadequate waste management practices. This study focuses on a subset of households within the city to analyze the situation. The volume of waste generated in Gazipur City Corporation is substantial and difficult to manage, causing widespread concern.

A structured waste management system is essential for collecting, disposing of, and recycling waste efficiently. The primary objective of this research is to determine per capita waste generation rates and compare recyclable and non-recyclable waste. Additionally, the study explores methods to convert waste into energy to help alleviate Gazipur City's electricity shortages. Seasonal and socioeconomic variations in waste generation will also be analyzed, as waste production is generally higher during the wet season due to increased food consumption, while it decreases slightly during the dry season.

Inorganic recyclable materials such as brick, wood, leather, glass, metal, polyethylene, and paper account for 25–35% of waste by mass, varying by source. Recyclable materials should be separated, and only organic and non-recyclable inorganic waste should be sent to final disposal sites. Given Gazipur's large population and high density, implementing an effective and sustainable waste management system is crucial. The study also highlights that Gazipur City Corporation, being relatively new, suffers from inadequate and inconsistent administrative and financial frameworks for waste management.

Proposed Solution:

To address municipal solid waste (MSW) management challenges in Gazipur, implementing waste-to-energy technologies such as incineration, landfills, and gas-to-energy plants is recommended. These solutions should consider factors like energy generation, processing time, and cost efficiency. For environmental sustainability and to reduce greenhouse gas emissions, waste incinerators equipped with filtration systems can be used to burn MSW at high temperatures, generating heat or electricity.

A comprehensive analysis of the energy output, processing time, and cost-effectiveness of each

technology is necessary to identify the most suitable waste-to-energy solution for Gazipur. By evaluating these factors and conducting feasibility studies, stakeholders can determine the optimal approach that balances efficiency and environmental concerns. Adopting these strategies will not only enhance MSW management but also address broader societal challenges in Gazipur City.

1.3 Objectives

- 1.To estimate the dimensions, composition, and characteristics of Gazipur City.
- 2.To assess the potential of Gazipur City for energy production and resource recovery.
- 3.To identify and evaluate technologies available in Gazipur City for converting waste into energy.
- 4.To determine the rate of waste generation in Gazipur City.
- 5.To estimate the total amount of waste generated through surveys.
- 6.To predict future waste generation rates and analyze the composition of solid waste.
- 7.To develop an accurate, improved, and refined scenario for waste management in the future.

Limitations

Several constraints have impacted this investigation. Although waste-to-energy systems have been studied in various city corporations, this research does not include a detailed examination of the nation's largest city corporation. Additionally, there is a lack of precise data on waste generation from businesses, industries, organizations, and street-sweeping activities within Gazipur City Corporation (GCC). The primary goal of evaluating the potential for energy generation lies in determining the system's effectiveness in transforming large amounts of waste into valuable energy resources.

Gazipur City Corporation's recent establishment has resulted in an insufficient and poorly documented municipal solid waste management system. Due to time limitations, data collection was restricted to a small sample of households across different GCC zones. This reliance on data obtained solely from questionnaire surveys limits the accuracy of the findings; collecting data from more households over a longer period would have yielded more reliable results. Additionally, drying the waste samples collected during the rainy season posed challenges, complicating the data collection and analysis processes.

1.4 Brief Methodology / Technologies/ Procedures

1. Gather info from GCC.
2. Analyze the data of organic and inorganic waste.
3. Waste category in sampling.
4. Moisture content determination.
5. Analyze high and low moisture organics.
6. Enter data into LandGem's tools.
7. Assess the landfill gas generated by LandGem.
8. Calorific value determination.
9. Measure the electrical energy generated by landfill gas.
10. Analyze the financial feasibility.
11. Ash content determination.
12. Analyze resource recovery from MSW.
13. Explore global and local aspects of solid waste generation.

Fig. 1.1: Methodology for LFGTE

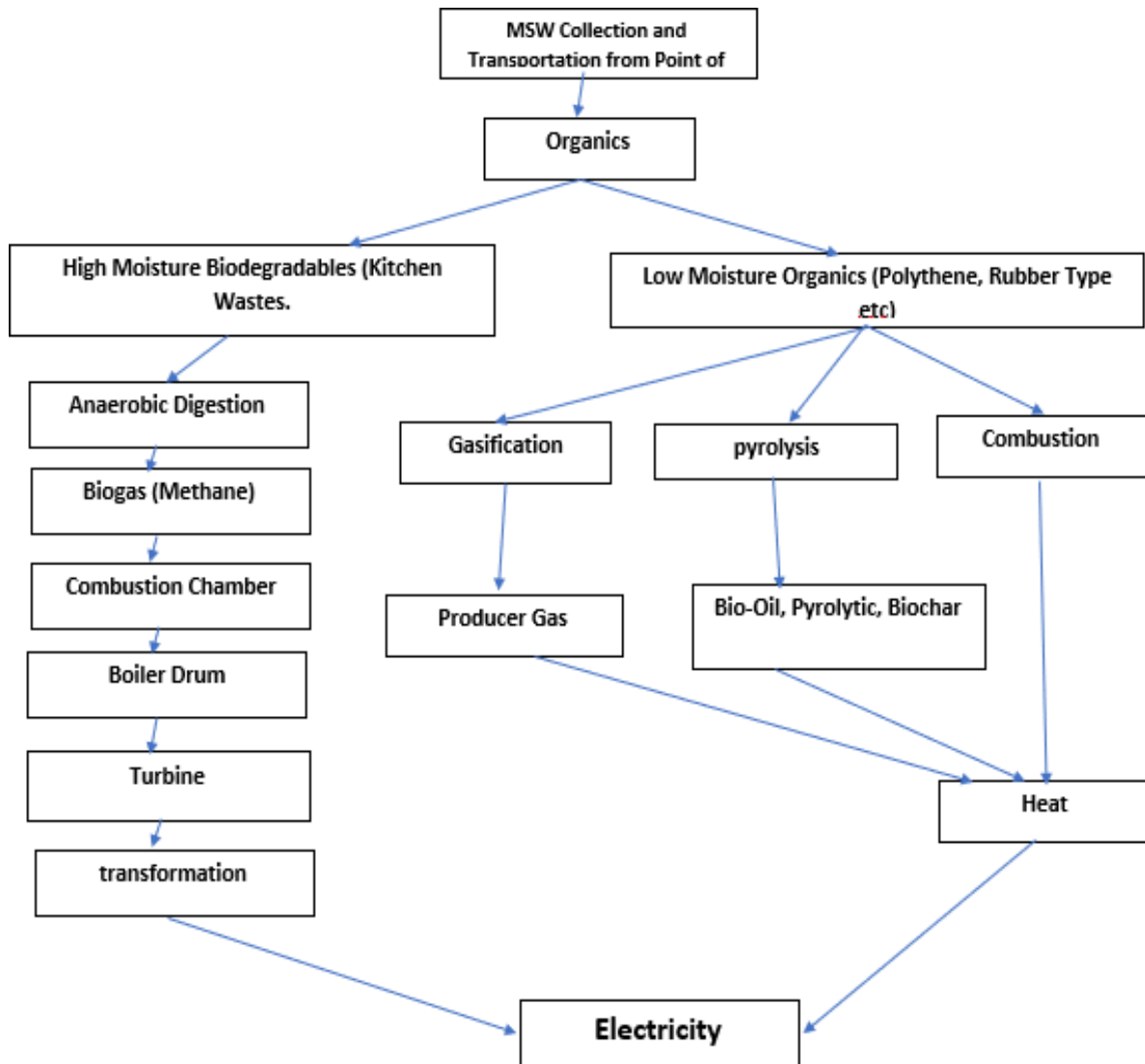


Fig. 1.2: Methodology for Waste to Incineration Technology

1. Research and Data Collection

- Collecting data on both organic and inorganic waste helps analyze waste composition, optimize composting and recycling efforts, and reduce environmental impact. This process also enhances waste management efficiency and identifies cost-saving opportunities.
- Public awareness and education initiatives will be undertaken to promote resource recovery and bioenergy production.

2. Feasibility Analysis

- Assess the economic feasibility of generating energy from municipal solid waste by evaluating potential revenue streams, collection and processing costs, and savings from reduced landfill use.
- Analyze the environmental impacts of various energy production methods, focusing on greenhouse gas emissions, waste reduction, and air pollution.
- Investigate the social acceptance of waste-to-energy projects in Dhaka City by involving communities, consulting stakeholders, and gathering public opinions.

3. Technology Assessment

- Compare different waste-to-energy technologies such as incineration, gasification, anaerobic digestion, and landfill gas recovery.
- Evaluate each technology's technical viability and scalability in light of Dhaka City's waste characteristics, existing regulations, and infrastructure.
- Consider factors like waste intake capacity, energy efficiency, processing capability, and compliance with local waste management regulations.

4. Policy and Regulatory Analysis

- Formulate policies to address the inefficient use of resources by Gazipur City Corporation.
- Align proposed policies with those of Gazipur City Corporation to ensure consistency.
- Prioritize public interests while addressing potential drawbacks.
- Develop policies that align with the goals of the regional government.

5. Financial Analysis

- Assess the economic viability of waste-to-energy systems.
- Conduct a financial review of various waste-to-energy models, including capital investment, operational costs, and potential returns on investment.
- Explore funding opportunities through public-private partnerships, international aid, and other financial sources to increase revenue streams.

6. Reporting and Recommendations

- Prepare a comprehensive report detailing the findings of financial, regulatory, technological, and feasibility analyses.
- Recommend the most suitable waste-to-energy technology for Gazipur City Corporation.
- Provide investors with detailed plans, keep them informed about challenges, and highlight lessons learned from past efforts.

1.5 Gantt Chart and Implementation Schedule

Work Breakdown Structure (WBS) for an Internet of Things (IoT)-based weather monitoring system tailored for a chicken farm:

1. Investigation and Information Gathering

- Review and analyze historical errors in the system.
- Collect and study data on waste types, breakdown rates, and content composition.
- Evaluate energy requirements and available power capacity to ensure efficient operation.

2. Technology Assessment

- Identify future-relevant technologies, considering their sequence and efficiency.
- Discuss potential improvements in the current technology framework.
- Calculate and analyze computational capacity along with energy efficiency for the proposed system.

3. Regulatory and Policy Analysis

- Identify obstacles that could hinder proper implementation and develop solutions to mitigate them.
- Propose incentives and recommend policy updates to facilitate smooth operations.

4. Financial Analysis

- Conduct a financial review of the technologies being evaluated.
- Explore potential funding opportunities and resources.
- Create a financial model to project scenarios and assess feasibility.

5. Summaries and Recommendations

- Document all findings in a comprehensive report.
- Provide recommendations for replacing outdated technologies and upgrading to more efficient systems

1.5 Gantt chart

Months/Task	1-2	3-4	5-6	7-8	9-10	11-12
1. Project planning	Done					
2. Literature Review		Done				
3. Data research and collection		Done	Done			
4. Data preprocessing				Done		
5. Calculation				Done		
6. Final Documentation					Done	

1.6 Organization / Structure of the Report

1. Introduction

- **Problem Statement:**

Articulation of the challenges related to municipal solid waste (MSW) management and energy generation in Gazipur City.

- **Study Objectives:**

Goals for evaluating the potential of power generation from MSW in Gazipur.

- **Significance:**

Importance of the thesis in addressing Gazipur's waste management and energy requirements.

2. Review of Literature

- Overview of previous research on power generation from MSW, focusing on technological viability and economic feasibility.
- Examination of Gazipur City's existing waste management practices and their limitations.
- Identification of global best practices and technologies applicable to Gazipur.

3. Methodology

- **Research Design:**

Description of the research methods, including data collection and analysis.

- **Study Area:**

Criteria for selecting Gazipur's waste management facilities as case studies.

Assessment Framework:

Framework to evaluate the feasibility and potential of MSW-to-energy technologies for Gazipur.

4. Waste Composition and Quantity Analysis

- Analysis of the composition, types, and quantities of MSW generated in Gazipur City.
- Energy potential estimation based on current and projected waste generation trends.

5. Technological Alternatives for Producing Power

- Evaluation of various technologies, such as incineration, anaerobic digestion, gasification, and landfill gas recovery.
- Comparative analysis of these technologies in terms of technical feasibility, environmental impact, and appropriateness for Gazipur City.

6. Feasibility Assessment

- Analysis of potential challenges in implementing waste-to-energy (WTE) projects in Gazipur.
- Assessment of social and environmental implications of WTE projects.
- Evaluation of financial and economic viability for large-scale WTE initiatives.

7. Best Practices and Case Studies

- Examination of successful WTE projects implemented in other cities or countries.
- Lessons learned and their relevance for adapting and implementing similar projects in Gazipur.

8. Policy and Regulatory Framework

- Review of Gazipur City's current policies and regulations regarding waste management and energy production.
- Recommendations for policy reforms and incentives to encourage WTE projects in Gazipur.

9. Analysis of Data and Outcomes

- Presentation of collected data on Gazipur's waste composition, energy potential, and feasibility studies.
- Interpretation of findings regarding Gazipur's capacity to generate electricity from MSW.

10. Discussion

- Critical analysis of findings, addressing constraints and implications for Gazipur.
- Comparison with existing waste management and energy production methods in Gazipur.
- Identification of opportunities for further research and development.

11. Conclusion

- Summary of objectives, findings, and their relevance to Gazipur's waste-to-energy potential.
- Overview of the study's contributions to waste management and energy sustainability in Gazipur City.

12. Recommendations

- Suggestions for advancing research and technological adoption in MSW-based power generation for Gazipur.
- Policy recommendations for stakeholders, waste management authorities, and local government.

13. Appendix

- **Technical Details:**
Detailed descriptions of examined WTE technologies.
- **Supplementary Data:**
Graphs, charts, and tables supporting the findings.
- **Regulatory References:**
Relevant policy documents and regulations in Gazipur City.

This outline adapts the report's focus to Gazipur City while preserving its comprehensive structure and emphasis on addressing MSW challenges and energy opportunities.

Chapter 2: Literature Review

2.1 Introduction and Context

The management of municipal solid waste (MSW) is a critical issue worldwide, particularly in rapidly urbanizing regions like Gazipur, Bangladesh. Gazipur City Corporation (GCC) is responsible for managing approximately 4,000 tons of waste daily, of which only 40–50% is adequately collected and disposed of[22]. The remaining waste is left untreated, leading to severe environmental and health concerns. With urban waste generation projected to rise significantly, there is an urgent need for sustainable waste management solutions that integrate waste-to-energy (WTE) technologies. This chapter reviews the key WTE methods—incineration, anaerobic digestion (AD), gasification, pyrolysis, and landfill gas (LFG) recovery—to provide a foundation for addressing the challenges in Gazipur.

2.2 Overview of Existing Research

Existing research underscores the significant potential of waste-to-energy (WTE) technologies in managing municipal solid waste (MSW) while generating renewable energy. Incineration, a widely adopted method, can reduce waste volume by over 85% and recover energy in the form of electricity or heat. In Europe, Germany leads with an installed municipal waste energy capacity of approximately 1,023 megawatts as of 2023, contributing to the continent's total capacity of 5.04 gigawatts.[23]

Anaerobic digestion (AD) focuses on converting organic waste into biogas, offering an environmentally friendly alternative with reduced emissions. Germany is Europe's largest biogas producer, with over 5,900 biogas plants operating nationwide as of 2010.[24]

Gasification and pyrolysis, advanced thermochemical methods, are particularly suitable for mixed waste types, producing syngas or bio-oil for energy applications. These technologies are gaining traction due to their higher energy efficiency, with gasification generating between 500–800 kWh per ton of waste and pyrolysis producing 400–600 kWh per ton[25].

Landfill gas (LFG) recovery harnesses methane emissions from landfills, contributing to both energy generation and greenhouse gas reduction. In Europe, the adoption of LFG recovery varies, with countries like the United Kingdom implementing projects to inject biogas into the national grid[26]

Globally, the adoption of these technologies varies. Europe has been a leader in incineration, with Germany having the greatest installed capacity of municipal waste energy plants in 2023[27]. Anaerobic digestion is widely used in countries like Germany and Italy, with Germany being Europe's largest biogas producer. Gasification and pyrolysis are less mature but are gaining traction due to their higher energy efficiency. In developing countries like Bangladesh, the adoption of WTE technologies remains limited due to infrastructural and financial constraints.

2.3 Identification of Research Gaps

Despite advancements in WTE technologies, several research gaps exist, particularly in the context of Bangladesh:

- Limited studies have explored the integration of multiple WTE technologies to address diverse waste streams.
- Economic feasibility analyses specific to Gazipur's socio-economic conditions are sparse.
- The potential of landfill gas recovery remains underexplored in Bangladesh, despite its significant methane emissions.
- Research on optimizing WTE systems to reduce environmental impact and increase energy recovery in developing countries is inadequate.

This review aims to bridge these gaps by analyzing the feasibility of integrating incineration, AD, and LFG recovery in Gazipur.

2.4 Theoretical and Conceptual Framework

The Integrated Sustainable Waste Management (ISWM) framework underpins this study, emphasizing waste reduction, reuse, recycling, recovery, and disposal. ISWM advocates for a combination of technological, institutional, and social interventions to achieve sustainable waste management. This framework aligns with the principles of circular economy, focusing on resource efficiency and waste minimization.

In the context of WTE technologies, the study leverages thermodynamic principles to evaluate energy recovery potential and environmental science concepts to assess emissions and sustainability.

2.5 Comparative Analysis of Technologies

Incineration:

- **Strengths:** High waste reduction efficiency, significant energy recovery, and pathogen elimination.

- **Weaknesses:** High capital and operational costs, potential environmental concerns (e.g., dioxins), and public resistance.

- **Applications:** Widely adopted in Europe; the planned Gazipur WTE plant (42.5 MW) demonstrates its feasibility in Bangladesh.

Anaerobic Digestion:

- **Strengths:** Low emissions, nutrient recycling, and suitability for organic waste.

- **Weaknesses:** Limited to biodegradable waste, slower process, and scalability challenges.

- **Applications:** Limited to biodegradable waste, slower process, and scalability challenges.

Gasification and Pyrolysis:

- **Strengths:** High energy efficiency, ability to process mixed waste, and production of syngas or bio-oil.

- **Weaknesses:** High technological and infrastructural demands, less mature than incineration or AD.

- **Applications:** Emerging technologies with potential for high-impact adoption in Gazipur.

Landfill Gas Recovery:

- **Strengths:** Utilizes existing landfills, reduces methane emissions, and provides renewable energy.

- **Weaknesses:** Methane leakage, air intrusion, and dependency on landfill design.

- **Applications:** Widely used globally; Gazipur's existing landfill offers an opportunity for implementation.

2.6 Connection to Current Research

This study seeks to evaluate the integration of WTE technologies in Gazipur to address its dual challenges of waste management and energy scarcity. By analyzing waste composition, methane generation potential, and energy recovery efficiency, the research aims to develop a sustainable WTE model tailored to Gazipur's unique needs.

2.7 Critical Evaluation

Each WTE technology has distinct advantages and challenges, especially in the context of developing countries like Bangladesh. Incineration offers high waste reduction and energy

recovery but faces high costs and environmental concerns. AD is environmentally friendly but limited to biodegradable waste and has scalability issues. Gasification and pyrolysis provide high energy efficiency but require advanced technology and significant investment. Landfill gas recovery is cost-effective and environmentally beneficial but offers limited energy output. A hybrid approach, combining these technologies, could provide the best solution for Gazipur, addressing both waste and energy challenge

Chapter-03

METHODOLOGY

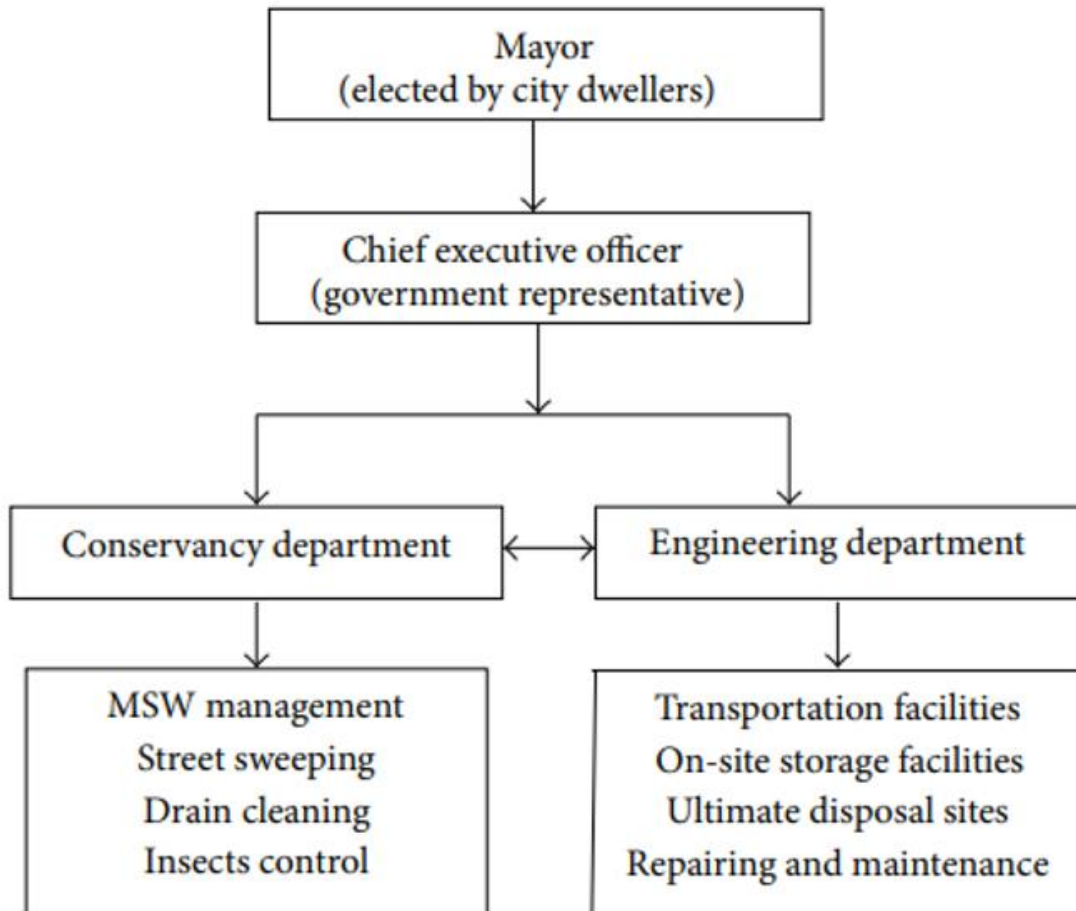


Figure-3.1: General Setup of MSW Management in the City Corporation of Bangladesh

3.1 Municipal Solid Waste (MSW)

Municipal Solid Waste (MSW) refers to the waste produced by households, businesses, institutions, and industries, and it is mainly managed by local governments. MSW consists of everyday waste from homes, businesses, hospitals, public spaces, and street cleaning activities. While fossil fuels are the primary global energy source, there is increasing interest in renewable energy sources, such as biomass, to address environmental concerns related to fossil fuel consumption. MSW is seen as a potential source of renewable energy because it contains a large proportion of biodegradable organic matter.

3.2 Study Area Description

As of July 2006, Bangladesh was the seventh most populous country in the world, with a population of 147.36 million. The country is undergoing rapid urbanization, with a significant migration from rural to urban areas each year. The population growth rate is about 1.4% annually, while urban areas are growing by 3.27% each year. Currently, about 28% of the population lives in urban areas, which totals 40 million people. By 2040, the urban population is expected to increase to 116 million, making up 50% of the total population. In 2005, Bangladesh's urban areas generated 13,332.89 tons of waste per day. By 2025, it is projected that daily waste generation will rise to 47,000 tons due to the increasing urban population, which will represent 40% of the national population.

3.3 Gazipur City Corporation (GCC)

In 2013, Gazipur City Corporation (GCC) was established by merging the municipalities of Gazipur and Tongi with surrounding rural areas like Bashan, Gachha, Kashimpur, Kayaltia, Konabari, and Pubail. The total area of GCC is 329.53 km² (127.23 sq mi). Gazipur experiences temperatures ranging between 10-12°C in cooler months and 38-40°C during the hottest months of June and July. The city receives about 2,400 mm of annual rainfall. As of the latest census, the population of GCC is 2,674,697, with 52% male and a literacy rate of 65-70% for those over seven years old. The city covers 167.83 km², and its road network includes 2,420 km of paved roads and 1,215 km of unpaved roads.

Gazipur generates approximately 600 tons of MSW every day. However, 80-90% of this waste is dumped in open areas, and the remaining waste is either uncollected or scattered across the city as litter. The city's drainage system includes both covered and uncovered drains. While newer developments have covered drains, older areas still feature uncovered drains. These drains collect grey water from households,

businesses, and industries, but some MSW ends up in the stormwater drains, which ultimately flow into open fields. Only 10 of the 57 wards in Gazipur have door-to-door waste collection services.

GCC operates one landfill site, covering 8 acres and 15 feet deep, located in Khaikur. In addition, there are about 1,500 dustbins and 300 collection points scattered throughout the city to manage waste. Despite these facilities, a significant amount of waste is still discarded in open spaces due to inadequate resources and outdated waste management systems. The rapid urbanization, fueled by rural-to-urban migration, has led to slum development and unregulated waste production, creating even more challenges for waste management in Gazipur and other major cities of Bangladesh.

The current waste management system in Gazipur is insufficient and has negative consequences for public health, safety, and the environment. Effective waste management requires proper systems for collection, disposal, and storage, but the city's infrastructure is overwhelmed by the growing urban population. In fact, around 50% of daily waste in Bangladesh's six major city corporations goes unmanaged. Public-private partnerships could play an important role in improving urban governance and waste management practices. The waste generated in Gazipur is mostly used for landfilling, and the current system needs significant improvements for more efficient municipal solid waste management (MSWM).

In terms of electricity, Gazipur faces a shortage, with a demand of about 400 MW, but the Power Development Board only supplies 250 MW. Without power generation units, the city frequently experiences load shedding and unreliable power. This instability is affecting industrial production, with mills and factories experiencing slowdowns. The demand for backup power devices is rising, especially in the city's outskirts. As a result, finding alternative sources of electricity generation has become crucial.

3.4 Integrated Sustainable Waste Management (ISWM)

The management of municipal solid waste (MSW) poses significant challenges for Gazipur City Corporation, affecting its economic, environmental, and social well-being. The city's struggle to manage its growing waste stems from inadequate infrastructure, weak environmental controls, poor institutional frameworks, limited understanding of complex systems, and insufficient sanitation.

An Integrated Sustainable Waste Management (ISWM) approach is essential to address these issues. ISWM emphasizes adopting sustainable technologies and practices across all stages of waste management, including source separation, collection, transportation, material recovery, treatment, resource recovery, and final disposal. Legalizing informal waste management systems, encouraging public participation, and introducing partial privatization are key to achieving this goal.

In industrialized nations, waste management typically follows a hierarchy: reduce, reuse, recycle, recover, and landfill. However, Bangladesh's national waste strategy primarily focuses on the 3Rs—reduce, reuse, and recycle—leaving room for further development in waste management practices.

3.4.1 Disposal of MSW

Proper disposal of MSW is vital to prevent environmental degradation and land pollution. In developing countries, open dumping is a common yet unsustainable practice. Adopting systematic disposal methods is crucial to mitigate these risks.

3.4.2 Composting

Composting, one of the oldest waste management techniques, is a natural process where microorganisms break down organic waste, such as plant and food materials, into nutrient-rich compost. This method is effective for organic waste but tends to be slow.

3.4.3 Landfilling

Landfilling is a widely used, cost-effective method for waste disposal, particularly for leveling low-lying areas for future use. However, it releases harmful gases like methane, contributing to environmental pollution. In Bangladesh, while some resource recovery plants exist, landfilling remains the dominant method of waste disposal.

3.4.4 Waste-to-Energy (WTE) Plants

Globally, the use of biomass for energy is increasing, and MSW serves as a renewable energy source for electricity generation. Waste-to-energy (WTE) plants convert the organic fraction of MSW into power through thermo-chemical and bio-chemical processes. Key WTE technologies include gasification, anaerobic digestion, and combustion. These methods can reduce waste volume by up to 90% while addressing both waste disposal and energy generation challenges. Efficient use of natural resources through WTE contributes to sustainable development.[16]

3.5.1 Incineration

Incineration, the most established technology for energy recovery from waste, involves burning waste in furnaces to produce heat for electricity or thermal energy. By-products include ash and exhaust gases. Ash can be processed to recover metals for recycling, while the remaining material can be used in construction. Most modern incineration plants have an energy efficiency of about 30%, but new technologies, such as integrated WTE gas turbines, aim to increase efficiency beyond 40%.

While incineration is effective in reducing waste volume by up to 90% and handling various waste types, it has its drawbacks. These include high construction costs, environmental concerns, and public opposition due to the release of harmful emissions like dioxins and toxic gases. However, advancements in technology and stricter regulations have significantly reduced these emissions in recent years.

Incineration has been successfully implemented in Europe, with leading investors including France, Germany, the UK, Italy, and Sweden. In 2015, 26% of waste in the European Union (EU) was converted to energy, contributing 1.3% of electricity and 8.9% of heat consumption. In 2012, 409 WTE plants in the EU processed 74 million tons of waste, generating 30 TWh of electricity and 74 TWh of heat.

In Gazipur, the contribution of waste incineration to electricity generation is expected to be minimal compared to Bangladesh's overall capacity. The planned Gazipur WTE plant, generating 42.5 MW of power, will account for less than 0.2% of the nation's total installed capacity of over 25,000 MW.[17]

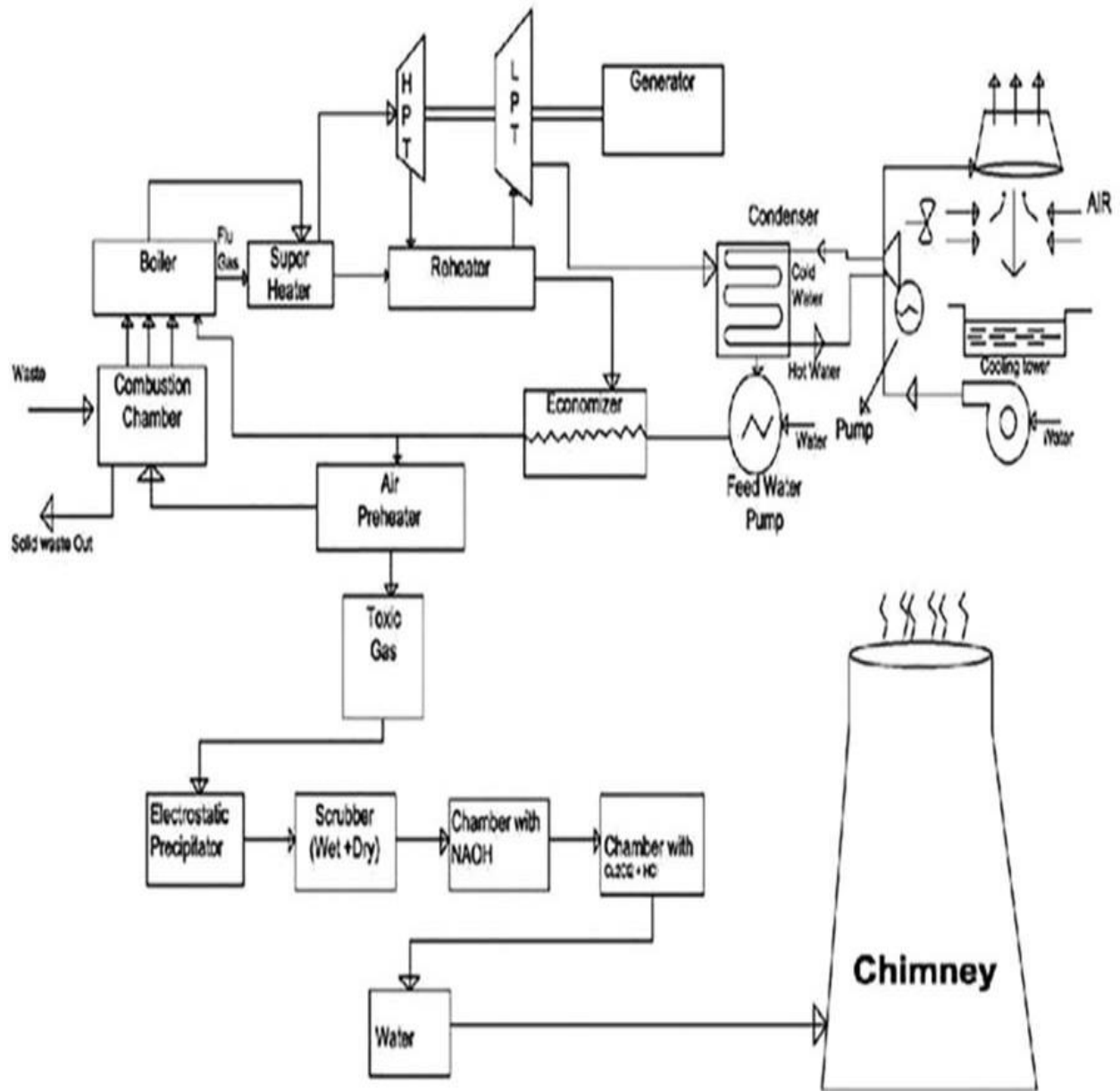


Figure -3.2 : Incineration Process

3.5.2 Anaerobic Digestion

Anaerobic digestion is a waste-to-energy technology that involves breaking down biodegradable materials using bacteria in the absence of oxygen. This process produces biogas, a renewable energy source composed mainly of methane and carbon dioxide. Compared to incineration, anaerobic digestion offers advantages such as lower carbon dioxide emissions, reduced odor, and the ability to convert organic waste into soil conditioners. From a lifecycle perspective, anaerobic digestion is also more environmentally attractive than incineration.

However, this process has limitations. It is relatively slow and can only handle biodegradable waste, making it impractical as the sole solution for managing all waste in a country. Globally, there were around 12,000 biogas plants in 2016, a number expected to grow to 15,000 by 2025, with 90% located in Europe. Leading markets include Germany, France, Italy, and Poland. Despite its potential, anaerobic digestion is less mature and less widely adopted than incineration, particularly in urban settings where implementation poses unique challenges.

Currently, Gazipur City Corporation lacks a large-scale anaerobic digestion plant, focusing instead on waste-to-energy (WTE) through incineration. However, anaerobic digestion remains a promising future option for producing biogas and electricity from organic waste. If implemented in Gazipur, an anaerobic digestion plant processing 500 tons of organic waste daily could generate 50–100 MWh of electricity. This would represent approximately 0.2%–0.4% of the city's total electricity needs from waste-to-energy sources, with the impact nationally being even smaller. Actual contributions would depend on the volume and efficiency of the plant.

3.5.3 Gasification and Pyrolysis

Gasification involves converting organic materials into a gas mixture (syngas) and a solid by-product (char) at temperatures above 650°C. Syngas, which has high energy content, can be used for power generation or biofuel production, while char consists of organic carbon and ash. Pyrolysis, on the other hand, is the thermal decomposition of waste at 400–1000°C with limited or no oxygen. It produces three outputs: pyrolysis gas, liquid, and solid coke.

Both technologies can process various types of municipal solid waste (MSW) and have similar waste-to-energy (WTE) efficiency. However, gasification tends to be slightly more energy-efficient, converting 1 ton of waste into 500–800 kWh of electricity, compared to 400–600 kWh for pyrolysis, depending on the waste type and reactor efficiency. Despite their potential, these methods are less mature than incineration and anaerobic digestion.

For Gazipur City Corporation, which generates 2,500–3,000 tons of waste daily, gasification or pyrolysis could produce 1,000–2,400 MWh of electricity per day. While this would account for a small fraction of Bangladesh’s total energy supply, it could significantly address local energy demands. If fully implemented, these methods could contribute 0.5%–1% of Gazipur’s total electricity needs, with further potential depending on advancements in waste-to-energy technology and optimization of the processes.[18]

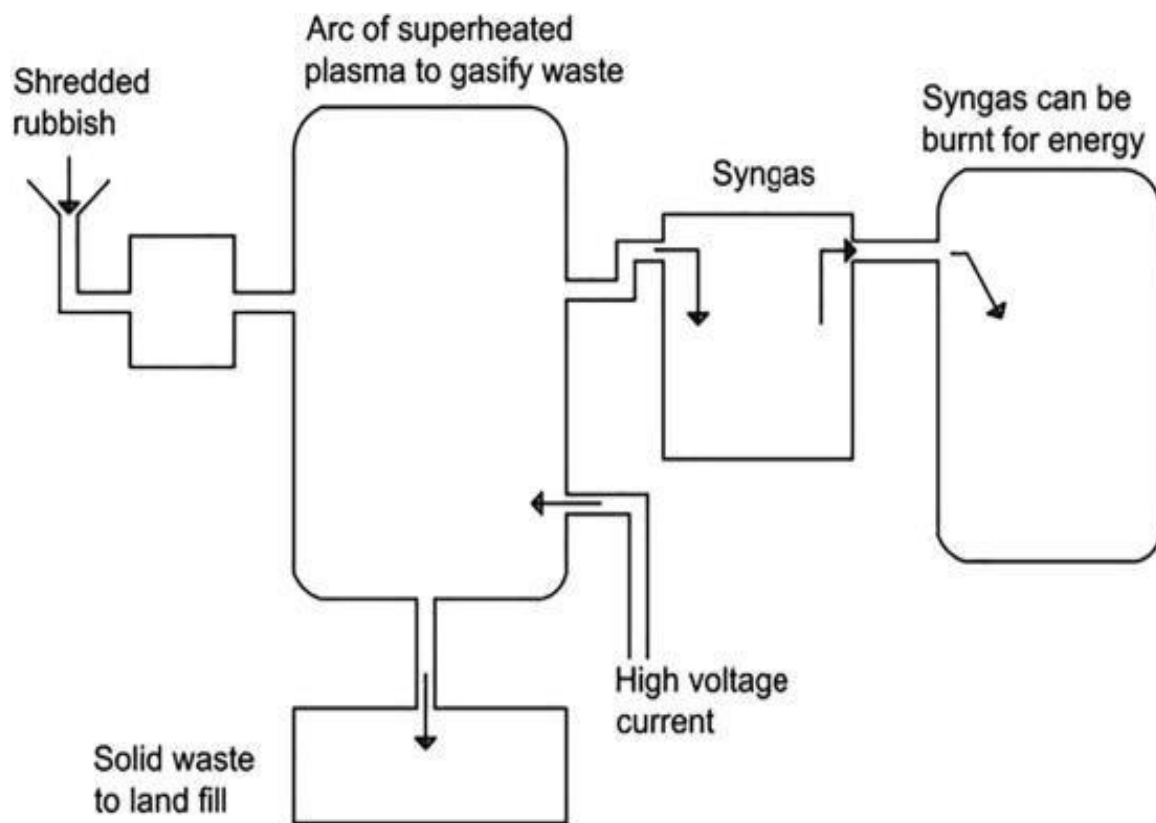


Figure-3.3 Gasification Process

3.5.4 Biochemical Conversion

Biochemical conversion is a more eco-friendly method of generating energy from waste compared to other techniques. It involves using microorganisms and enzymes to break down waste and convert it into energy. This category includes methods like anaerobic digestion and composting. In anaerobic digestion (AD), organic waste is used as feedstock, and microorganisms decompose it in the absence of oxygen, reducing waste volume and producing biogas.

In Gazipur, incineration remains the primary method for generating electricity from waste, including the upcoming 42.5 MW Waste-to-Energy (WTE) plant. Biochemical methods, such as anaerobic digestion, contribute a relatively small portion of total WTE output, often through smaller-scale biogas plants. It is estimated that biochemical conversion accounts for less than 5–10% of total waste-to-energy production. However, more precise data is needed to confirm this contribution.[19]

3.5.5 Thermo-Chemical Conversion

Thermo-chemical conversion processes transform agricultural, industrial, and residential waste into energy. Examples include agricultural waste like livestock slurry, lignocellulosic materials, and forest residues; industrial waste such as olive stones, almond shells, and plastic residues; and municipal waste or sewage sludge. Various thermo-chemical processes are used, including well-established methods like combustion, gasification, and pyrolysis, as well as less common techniques such as torrefaction, hydrothermal processing, cracking, and hydrocracking.

Depending on the method used, thermo-chemical conversion produces renewable energy in the form of heat, electricity, syngas, bio-char, or advanced biofuels. These processes also significantly reduce waste volume, often converting solid waste into ash. Additionally, high temperatures sanitize waste by destroying harmful microorganisms and stabilizing organic compounds. Although these processes offer high-value by-products, emissions must be carefully controlled, requiring advanced and costly technologies.

In Gazipur, most electricity from waste is expected to come from thermo-chemical conversion, particularly through incineration. The planned WTE plant will process 2,500–3,000 tons of waste daily to generate 42.5 MW of electricity. Thermo-chemical methods dominate large-scale WTE projects due to their efficiency in handling mixed waste. Over 90% of Gazipur's waste-derived electricity is likely to come from thermo-chemical processes, while biochemical methods like anaerobic digestion play a minor role.[20]

3.6 Methane Generation in Dumpsites or Landfills

The process of methane generation in landfills occurs in four stages:

1. **Hydrolysis:** In the presence of oxygen, aerobic bacteria break down complex organic materials like fats, carbohydrates, and proteins into simpler compounds, producing carbon dioxide as the main by-product. This stage continues until all oxygen is depleted.
2. **Acidogenesis:** Once oxygen is absent, anaerobic bacteria dominate, converting the simple compounds into acids (e.g., acetic, formic, and lactic acids) and alcohols (e.g., methanol and ethanol). This phase makes the landfill environment acidic and releases nutrients like nitrogen and phosphorus, which are utilized by various bacteria. Gaseous by-products include carbon dioxide and hydrogen.
3. **Acetogenesis:** Specialized bacteria called acetogens convert the acids formed earlier into acetate compounds, which serve as precursors for methane production.
4. **Methanogenesis:** Methanogenic bacteria use the acetate to produce methane, a key component of landfill gas (LFG).

Methane generated from LFG can be used to produce electricity through technologies like reciprocating internal combustion engines, fuel cells, and microturbines. Reciprocating engines are the most commonly used due to their affordability, efficiency, and compatibility with LFG. For larger-scale projects, gas turbines are preferred, while microturbines are suitable for smaller applications. Some plants combine electricity and thermal energy production (e.g., steam or hot water), referred to as cogeneration or combined heat and power (CHP) system.[21].

3.7 Design Specifications, Standards, Constraints:

I. Design Specifications

The technical specifications of a waste-to-energy plant in Gazipur City Corporation can change depending on the components selected and the particular requirements. The following are the main technological details to take into account:

1. **Waste Input Capacity:** The system's capacity to handle garbage in a given amount of time, usually expressed in tons per day (TPD) or kilograms per hour (kg/hr).
2. **Types of Waste Accepted:** a list of the waste kinds that the system is capable of processing efficiently, such as biomass, organic waste, and municipal solid waste (MSW).
3. **Energy Output:** The system's total electricity production, expressed in megawatts (MW) or kilowatts (kW).
4. **Efficiency:** The percentage of energy recovered from input waste, or the efficiency of the process used to generate power.
5. **Emissions:** Requirements for greenhouse gas emissions, particulate matter, and other pollutants produced during the process in order to comply with environmental laws.
6. **Residue Generation:** Amount and kind of residue (slag, ash, etc.) produced by the process, as well as how these residues are disposed of.
7. **Energy Recovery Technologies:** An explanation of the methods used to recover energy from garbage, including gasification and incineration.
8. **Cogeneration Potential:** the capacity to maximize energy efficiency by capturing and using waste heat for combined heat and power (CHP) applications.
9. **Scalability:** The system's capacity to adjust its size in response to changes in demand or waste feedstock availability.
10. **Maintenance Requirements:** The frequency and complexity of maintenance chores necessary to guarantee the system's smooth operation.
11. **Cost:** The power generation system's total cost-effectiveness, operating costs, and initial capital cost.

12. **Local Regulations and Standards:** Adherence to regional policies and guidelines concerning the handling of refuse, pollution, and energy production.

13. **Integration with Grid:** Compatibility and integration, including technical requirements for grid connection, with the regional electrical system.

14. **Reliability and Availability:** Measures for reliability, including availability percentage and mean time between failures (MTBF), guarantee steady electricity production.

15. **Safety Features:** A description of the safety measures and procedures in place to guard against mishaps and guarantee the well-being of both people and the environment.

16. **Remote Monitoring and Control:** Systems for remote monitoring and control are available to ensure the electricity production facility is operated and maintained efficient

II. Standards

Waste-derived power in Gazipur city must go by a number of rules and guidelines to guarantee environmental preservation, operational efficiency, and safety. The following are some important norms and regulations that are pertinent to the production of power from garbage in Gazipur city:

1. **Environmental Standards:** Respect for the environmental guidelines established by Bangladesh's Department of Environment (DOE). To maintain the quality of the air, these rules control the emissions of pollutants such as particulate matter, sulfur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs).

2. **Emission Limits:** Compliance with the Bangladesh National Environmental Quality Standards (NEQS) or other pertinent standards' specified emission limitations for air pollutants. These restrictions are meant to lessen the negative effects that waste-to-energy plants have on public health and air quality.

3. **Waste Management Regulations:** Adherence to the Gazipur City Corporation (GCC) trash management guidelines. In order to guarantee appropriate waste handling procedures, these regulations control the collection, transportation, treatment, and disposal of municipal solid waste (MSW).

4. **Occupational Health and Safety Standards:** Application of occupational health and safety regulations to safeguard employees engaged in garbage collection, sorting, and electricity production. This could involve

taking steps to stop mishaps, offer personal protective equipment (PPE), and guarantee secure working environments.

5. Electrical Safety Standards: Electrical systems are designed, installed, and maintained safely thanks to electrical safety standards. In order to avoid risks like fires and electrocution in a variety of situations, they address wiring, grounding, insulation, and device ratings.

6. Quality of Electricity: Adherence to requirements for the dependability and quality of power produced from trash. The voltage, frequency, and power quality specifications set forth by the Bangladesh Power Development Board (BPDB) or other pertinent regulatory bodies may fall under this category.

7. Grid Connection Requirements: Compliance with grid connection guidelines and protocols set forth by other regulatory agencies or the Bangladesh Energy Regulatory Commission (BERC). This guarantees the effective and safe integration of waste-derived electricity into the regional power system.

8. Monitoring and Reporting Requirements: The execution of protocols for monitoring and reporting aims to monitor emissions data, key performance metrics, and regulatory compliance. To show that standards and rules are being followed, regular reporting to regulatory bodies may be required.

9. Public Health Guidelines: Taking into account suggestions and guidelines for public health pertaining to waste management and electricity production. Measures to reduce noise, smells, and other possible effects on neighboring communities may be part of this.

10. Sustainable Development Goals (SDGs): Alignment with the Sustainable Development Goals (SDGs) by supporting sustainable energy generation methods and helping to build resilient, environmentally friendly cities, especially Goal 7 (Affordable and Clean Energy) and Goal 11 (Sustainable Cities and Communities).

III. Constraints

There are a number of issues with producing power from waste in Gazipur city that must be resolved for waste-to-energy projects to be implemented and run successfully. Among the principal limitations are:

1. Limited Waste Segregation: There are issues with garbage segregation at the source in Gazipur metropolis. It becomes challenging to recover useful resources from the waste stream and maximize the effectiveness of processes used in the production of energy without appropriate segregation.

2. Low Quality and Heterogeneity of Waste: The garbage produced in the city of Gazipur frequently has a high content of plastics, organic materials, and other heterogeneous materials. Waste-to-energy technologies may have difficulties as a result, since some components might be harder to process effectively or might provide less energy.

3. Land Constraints: The amount of land available in Gazipur city for waste management facilities, including as waste-to-energy plants, is restricted. Obtaining appropriate property for these kinds of projects can be difficult, and local groups may object because of worries about the effects on the environment and society.

4. Emissions and Air Quality Concerns: Particulate matter, sulfur dioxide (SO₂), nitrogen oxides (NO_x), and volatile organic compounds (VOCs) are among the pollutants that waste-to-energy facilities may release. Reducing emissions and maintaining adherence to air quality regulations are essential for reducing negative effects on the environment and human health.

5. Financial Viability and Funding: Waste-to-energy projects may have lengthy payback periods and call for a sizable upfront investment. It might be difficult to secure funding and guarantee the financial sustainability of projects, especially in an environment with limited resources like Gazipur City.

6. Technological Readiness and Expertise: Waste-to-energy projects must be implemented with access to the right technology and with knowledge in design, construction, and operation. The success of the project depends on securing the hiring of qualified staff and increasing local capability in waste-to-energy technologies.

7. Regulatory and Policy Framework: For waste-to-energy projects, the legal and policy framework controlling waste management and energy production in Gazipur city may provide obstacles or uncertainty. To make project execution easier, incentives for the development of renewable energy sources and clear, encouraging legislation are required.

8. Public Perception and Acceptance: Local communities may oppose waste-to-energy projects because of health dangers, smells, and environmental pollution concerns. Project success depends on interacting with stakeholders and raising public knowledge and acceptance of waste-to-energy technology.

9. Grid Integration Challenges: There may be technical difficulties when integrating waste-generated electricity into the local power system, especially with relation to grid stability, voltage regulation, and grid connection requirements. For a dependable supply of electricity, interoperability with the current grid infrastructure is crucial.

10. Operational and Maintenance Challenges: For waste-to-energy facilities to operate effectively and dependably, routine maintenance and operational monitoring are necessary. The limits of Gazipur city's infrastructure might make maintenance and repairs difficult due to limited resources and technical capacity

CHAPTER 4 WASTE TO ENERGY TECHNIQUE FROM MSW

4.1 Overview of the Study Area:

The Gazipur City Corporation was established in January 2013 and is composed of 57 wards drawn from most of the previous Gazipur Sadar Unions and the entire former Tongi Municipality. The Mayor and 76 elected Councilors administer the City Corporation. GCC is the largest city corporation of Bangladesh having an area of 329.53 square kilometer. Gazipur City Corporation is located in the center of the country. Connectivity of the capital city Dhaka with northern regions is through Gazipur City. It lies between 23°52'45" and 24°06'12" north latitudes and between 90°15'2" and 90°29'50" east longitudes. To identify the waste generation rate and waste characteristics of the whole city was divided into five zones. Corresponding zonal area and projected population can be obtained from Table . To propose an implementable waste management system it is very important to have a concrete data on population. Increasing population has a causal relationship with waste management in urban areas, because it has the potential to produce a large amount of solid waste, which is one of the challenges facing any urban area in the world. As the largest city in Bangladesh, GCC has a sizeable population, which leads to enormous waste generation. Waste generation and population number are intimately related. Choosing the best waste-to-energy technologies, and evaluating the possibility of resource recovery all depend on the precise estimation of population distribution throughout various zones. A key indicator of the region's ability to produce electricity is the amount of solid waste that is produced.[10]

4.2 Zonal Population and Waste Generation Data

Table 4.1 Zonal area and respective projected population

Zone	Area sq.km.	Protected Population				
		2016	2021	2023	2026	2036
Zone-I(TONGI)	32.60	650,598	805,998	867,526	959,819	1207,106
Zone-2 GACCHA &PUBAIL	75.93	448,944	556,177	598,635	662,323	832,963
Zone-3(GAZIPUR)	47.78	244,528	302,935	326,061	360,750	453,693
Zone-4 BASAN&KOYALTIA	104.20	347,144	430,064	462,894	512,139	644,086
Zone-5(KONABARI&KASHIMPUR)	61.28	326,343	404,924	435,156	481,450	605,490

Total	321.79	2017,556	2499,468	2690,273	2976,481	3743,338
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The table presents the zonal areas and projected populations for Gazipur City Corporation from 2016 to 2036. The city is divided into five zones, with each zone covering a specific area in square kilometers and showing significant population growth over the years.

Zone-1 (Tongi), spanning 32.60 sq. km, had a population of 650,598 in 2016, which is projected to grow steadily, reaching 1,207,106 by 2036. Zone-2 (Gaccha & Pubail), the largest zone at 75.93 sq. km, had a population of 448,944 in 2016, which is expected to increase to 832,963 by 2036. Zone-3 (Gazipur), covering 47.78 sq. km, had a smaller population of 244,528 in 2016, projected to rise to 453,693 by 2036. Zone-4 (Basan & Koyaltia), the second largest zone with 104.20 sq. km, showed a population of 347,144 in 2016, expected to reach 644,086 in 2036. Finally, Zone-5 (Konabari & Kashimpur), covering 61.28 sq. km, started with a population of 326,343 in 2016 and is projected to grow to 605,490 by 2036.[9]

The total area of Gazipur City Corporation is 321.79 sq. km. The total population across all zones was 2,017,556 in 2016 and is anticipated to grow to 3,743,338 by 2036. These projections highlight rapid urbanization and population growth in Gazipur, requiring strategic planning for infrastructure, resources, and services to accommodate future demands.

Table 4.2.1: Waste collection from GCC (tons/day)

Zone	Area sq.km.	Waste generation projection of household waste				
		2016	2021	2024	2026	2036
Zone-I(TONGI)	32.60	218	281	319	353	469
Zone-2(GACCHA & PUBAIL)	75.93	175.5	229	266	288	382
Zone-3(GAZIPUR)	47.78	91.5	122	136	153	203
Zone-4(BASAN&KOYALTIA)	104.20	115	150	173	188	250
Zone-5(KONABARI&KASHIMPUR)	61.28	117.5	154	178	193	257
Total	321.79	717.5	935	1072	1175	1561

The table illustrates the waste generation projection for household waste in Gazipur City Corporation (GCC), measured in tons per day, from 2016 to 2036. The data is divided across five zones, corresponding to their respective areas in square kilometers, showcasing the increasing waste management challenges driven by population growth.

Zone-1 (Tongi), covering 32.60 sq. km, generated 218 tons of waste per day in 2016. This is projected to

increase steadily to 469 tons per day by 2036. Zone-2 (Gaccha & Pubail), the largest zone with 75.93 sq. km, had a waste generation of 175.5 tons per day in 2016, expected to rise to 382 tons per day in 2036. Zone-3 (Gazipur), at 47.78 sq. km, generated 91.5 tons per day in 2016, with a projection of 203 tons per day by 2036. Zone-4 (Basan & Koyaltia), the second largest zone covering 104.20 sq. km, recorded 115 tons of waste per day in 2016, projected to grow to 250 tons per day by 2036. Zone-5 (Konabari & Kashimpur), covering 61.28 sq. km, started at 117.5 tons per day in 2016 and is expected to generate 257 tons per day by 2036.[9]

Collectively, GCC generated 717.5 tons of household waste per day in 2016, which is projected to increase to 1,561 tons per day by 2036. This data underscores the critical need for robust waste management systems to address the escalating demands in each zone, as well as the city as a whole. Proper planning and infrastructure are essential to mitigate environmental impacts and maintain urban sustainability.

4.3 Composition of High & Low Moisture

A range of factors, including the climate, socioeconomic conditions, and others, have a considerable impact on the composition of solid waste in different regions and cities. Designing adequate collection trucks and choosing proper waste treatment techniques require a thorough understanding of the composition of the solid waste in a given area. In our study, organic waste—which mainly consists of food and yard waste—was found to be the prevailing type of waste in the GCC. Additionally, all zones regularly contained combustible waste types such as paper, plastics, and textiles. Across all zones, it was common to find small quantities of non-combustible materials like glass, metal, wood, rubber, leather, and medical waste.

Table 4.3: Composition of solid waste in GCC

Component of Waste	Amount in (%)
Organic	54.92
Plastic Products	14.70
Paper	12.60
Textile and Wood	4.73
Leather and Rubber	1.54
Metal	1.56
Glass	1.14
Others	8.81

4.3.1 Waste from Household

Table 4. 3: Waste generation projection of household waste of GCC (tons/day)

Composition (% by weight)	Food & Yard Waste	Paper	Plastics/ Polythene	Glass	Metal	Textiles & Wood	Rubber & Leather	Others	Total
Cycle 1 (Jan-Feb)	77.03	5.65	8.21	0.96	0.86	4.51	0.40	2.35	100.00
Cycle 2 (February- March)	75.58	5.82	8.70	2.06	0.60	5.05	0.65	1.55	100.00
Average in Dry Season	76.31	5.73	8.46	1.51	0.73	4.79	0.53	1.95	100.00

The two cycles in our study were cycle 1, which was conducted for 1 month, and Cycle 2, which was conducted for 1 month during hot weather. organic percentage During cycle 2 the waste is slightly reduced, which can be Due to evaporation of moisture due to increased temperature. on the contrary, Cycle 2 saw a significant increase in the proportion of glass elements, which Probably related to the higher use of summer glassware. [10]Additionally, cycle 1 was a A high percentage of medical waste, suggesting that cold-related illnesses were high common at the time.

4.4 Energy Conversion Pathways

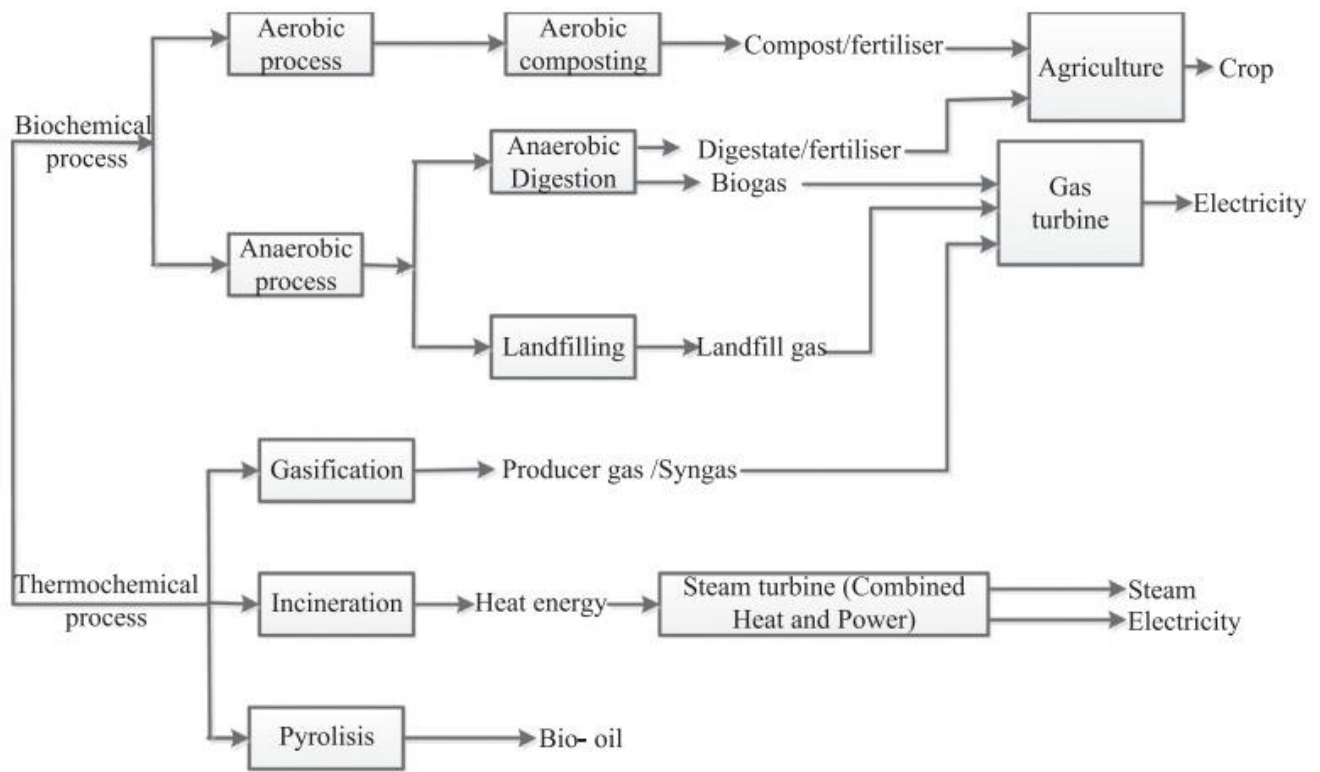


Figure 4.1: Energy conversion pathways from MSW

The figure represents the waste-to-energy (WTE) pathways and resource recovery processes, highlighting biochemical and thermochemical methods for managing organic waste. Biochemical processes are divided into aerobic and anaerobic pathways. The aerobic process leads to aerobic composting, which produces compost or fertilizer that can be applied in agriculture to enhance soil fertility and support crop production. Anaerobic digestion, another biochemical pathway, generates digestate as fertilizer and biogas, which can be used to produce electricity through gas turbines. Landfilling, a common anaerobic process, generates landfill gas composed of methane and carbon dioxide, which can also be converted into energy.

Thermochemical processes include gasification, incineration, and pyrolysis. Gasification produces syngas or producer gas, which can serve as a fuel for energy production. Incineration converts waste into heat energy, which is utilized in steam turbines for combined heat and power (CHP) generation, producing both steam and electricity. Pyrolysis transforms organic materials into bio-oil, a liquid fuel that can be refined for various applications.

This diagram effectively showcases the interconnected pathways of organic waste management and energy recovery, emphasizing the potential of integrated systems to reduce waste while producing valuable energy and agricultural inputs. These processes underline the importance of sustainable waste management

strategies in mitigating environmental impacts and optimizing resource use.

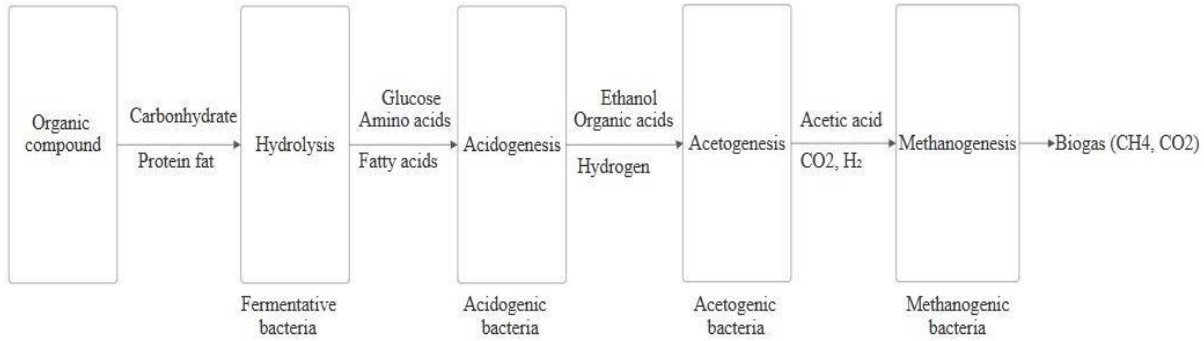


Figure 4.2 : Process Diagram of LFGTE technology.

The diagram illustrates the anaerobic digestion process involved in Landfill Gas to Energy (LFGTE) technology. Organic compounds, such as carbohydrates, proteins, and fats, undergo decomposition through microbial activity. Initially, these compounds are broken down into simpler substances like sugars, amino acids, and fatty acids. These intermediates are further converted into volatile fatty acids, ethanol, hydrogen, and carbon dioxide. [11] In the final stage, methanogenic bacteria transform these products into methane (CH₄) and carbon dioxide (CO₂), forming biogas. This biogas, primarily composed of methane, is then collected and utilized as a renewable energy source.

Estimation Methodology:

LandGEM employs a first-order decay equation to estimate methane generation:

$$Q_{CH_4} = \sum_{i=1}^n \sum_{j=0.1}^1 K L_o \left(\frac{M_t}{10}\right) e^{-kt_{ij}} \quad (1)$$

Where:

- Q_{CH_4} : Estimated methane generation rate (m³/year)
- $i = 1$ year time increment
- $n = (\text{year of the calculation}) - (\text{initial year of waste acceptance})$

- $j = 0.1$ year time increment
 - k : Methane generation rate constant (year^{-1})
 - $L_o =$ potential methane generation capacity (m^3 / Mg)
 - $M_i =$ mass of waste accepted in the i^{th} year
- $t_{ij} =$ age of the j^{th} section of waste mass M_i accepted in the i^{th} year (decimal years, e.g., 3.2 years)

Estimate The Landfill Gas Produced in Landfill by LandGem:

The Landfill Gas Emissions Model (LandGEM) is a tool developed by the U.S. Environmental Protection Agency (EPA) to estimate gas emissions from municipal solid waste (MSW) landfills. It utilizes a first-order decay rate equation to predict the generation of landfill gases, primarily methane (CH_4) and carbon dioxide (CO_2), over time. [12]

LandGEM is designed to estimate the generation and emission of landfill gases, primarily methane (CH_4) and carbon dioxide (CO_2), from MSW landfills over time. It is often used for environmental assessments and landfill gas recovery project feasibility studies.[7]

LandGEM has been widely used in academic research to estimate landfill gas emissions. For instance, a study titled "Estimation of Gas Emissions using the LandGEM Model from the Landfill of Baft County, Kerman, Iran" utilized LandGEM to predict gas emissions and assess energy recovery potential. [8]

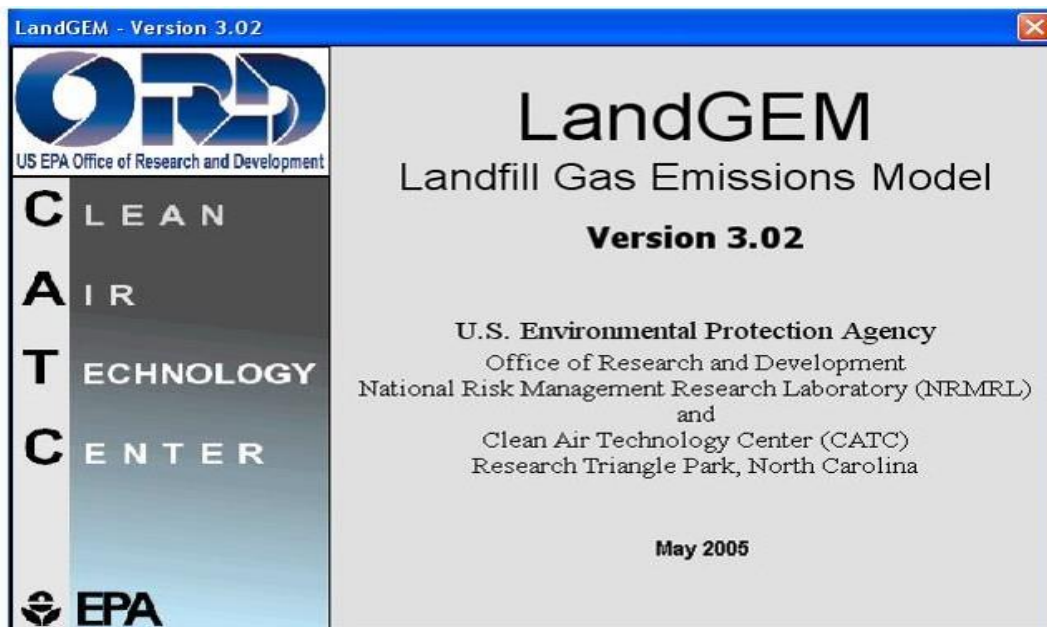


Figure 4.3 : LandGEM Landfill gas emission model.

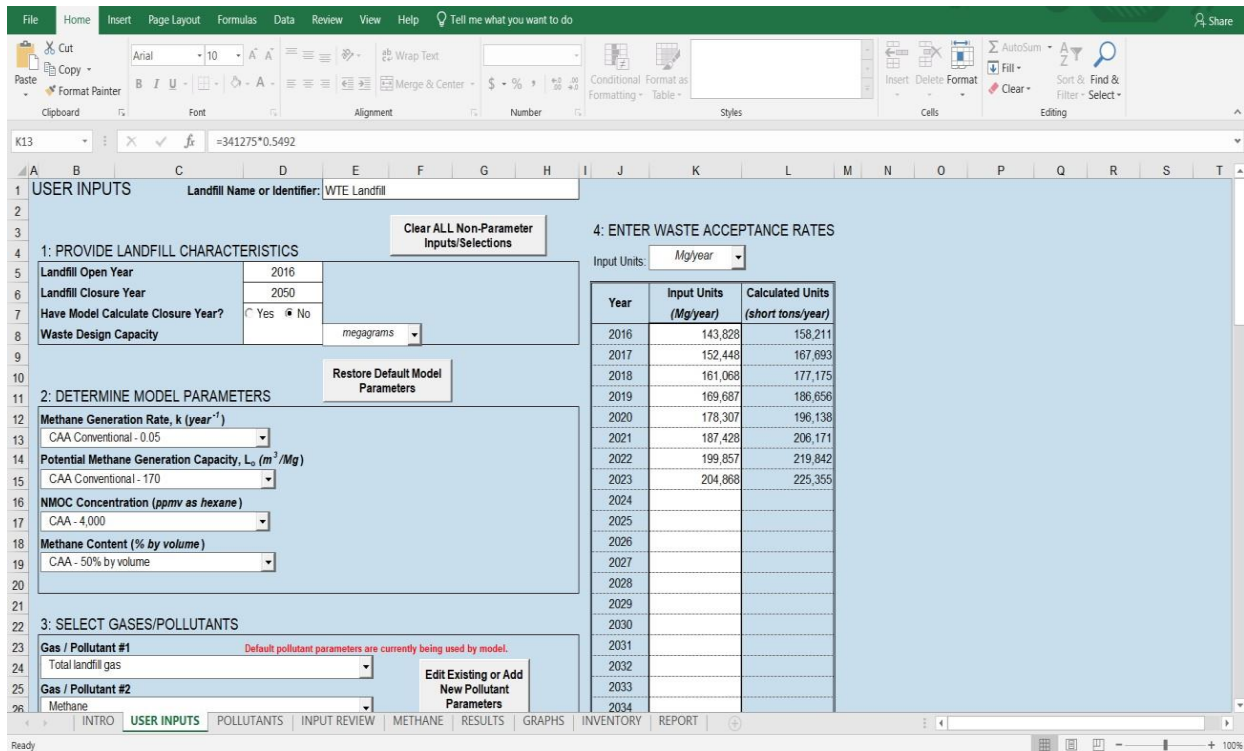


Figure 4.4: LandGem input data and Model Parameter for LFGTE

The provided image showcases the "User Inputs" section of the Landfill Gas Emissions Model (LandGEM), a widely used tool for estimating methane and other greenhouse gas emissions from municipal solid waste (MSW) landfills. This interface allows researchers to input landfill-specific data, configure gas generation parameters, and input historical or projected waste acceptance rates to simulate gas generation dynamics over the operational lifespan of a landfill.

In the displayed example, the landfill is shown to have commenced operations in 2016, with a planned closure in 2050. The waste acceptance rate increases over time, starting at 143,828 megagrams (Mg) in 2016 and reaching 204,868 Mg in 2023, indicating a gradual growth in waste disposal activities. Additionally, the interface highlights the methane generation rate (k) of 0.05 yr^{-1} , a typical value for landfills in arid climates, and the potential methane generation capacity (L_0) of 170 m^3 per megagram, reflecting standard default parameters. The NMOC concentration is set at 4,000 ppmv, and methane is modeled as comprising 50% of the landfill gas by volume, aligning with typical landfill gas compositions.[6]

This system is crucial for modeling gas emissions over time, allowing researchers and environmental managers to estimate the environmental impacts of landfills and design appropriate gas collection systems. The inclusion of both calculated and input waste acceptance rates, along with adjustable methane generation

parameters, makes the model highly flexible and applicable to a range of landfill conditions. By providing a clear and interactive interface, LandGEM serves as a robust tool for environmental impact assessments and the development of mitigation strategies for landfill gas emissions.

13	CAA Conventional - 0.05	
14	Potential Methane Generation Capacity, L_0 (m^3/Mg)	
15	CAA Conventional - 170	
16	NMOC Concentration (<i>ppmv as hexane</i>)	
17	CAA - 4,000	
18	Methane Content (% by volume)	
19	CAA - 50% by volume	
20		
21		
22	3: SELECT GASES/POLLUTANTS	
23	Gas / Pollutant #1	Default pollutant parameters are currently being used by model.
24	Total landfill gas	<input type="button" value="Edit Existing or Add New Pollutant Parameters"/> <input type="button" value="Restore Default Pollutant Parameters"/>
25	Gas / Pollutant #2	
26	Methane	
27	Gas / Pollutant #3	
28	Carbon dioxide	
29	Gas / Pollutant #4	
30	NMOC	
31		
32		
33	Description/Comments:	
34		
35		
36		
37		

Figure 4.5: Pollutant Parameters of LFGTE

The displayed section of the LandGEM interface illustrates the configuration of gases and pollutants that are modeled within the tool. This part of the software allows for the selection and customization of gases or pollutants associated with landfill gas emissions. The model includes predefined pollutant parameters for "Total landfill gas," "Methane," "Carbon dioxide," and "Non-Methane Organic Compounds (NMOCs)." Users can edit existing pollutant parameters or add new ones as required to suit specific landfill gas composition scenarios. Additionally, a feature to restore default pollutant parameters is included to ensure the model adheres to standard configurations when necessary.

This section is essential for specifying the composition of landfill gas, which significantly impacts the accuracy of emission estimates. By allowing users to adjust pollutant parameters, the software provides

flexibility to account for variations in waste composition and site-specific conditions. Methane and carbon dioxide, the primary components of landfill gas, are critical in estimating greenhouse gas contributions, while NMOCs are crucial for assessing air quality and regulatory compliance.

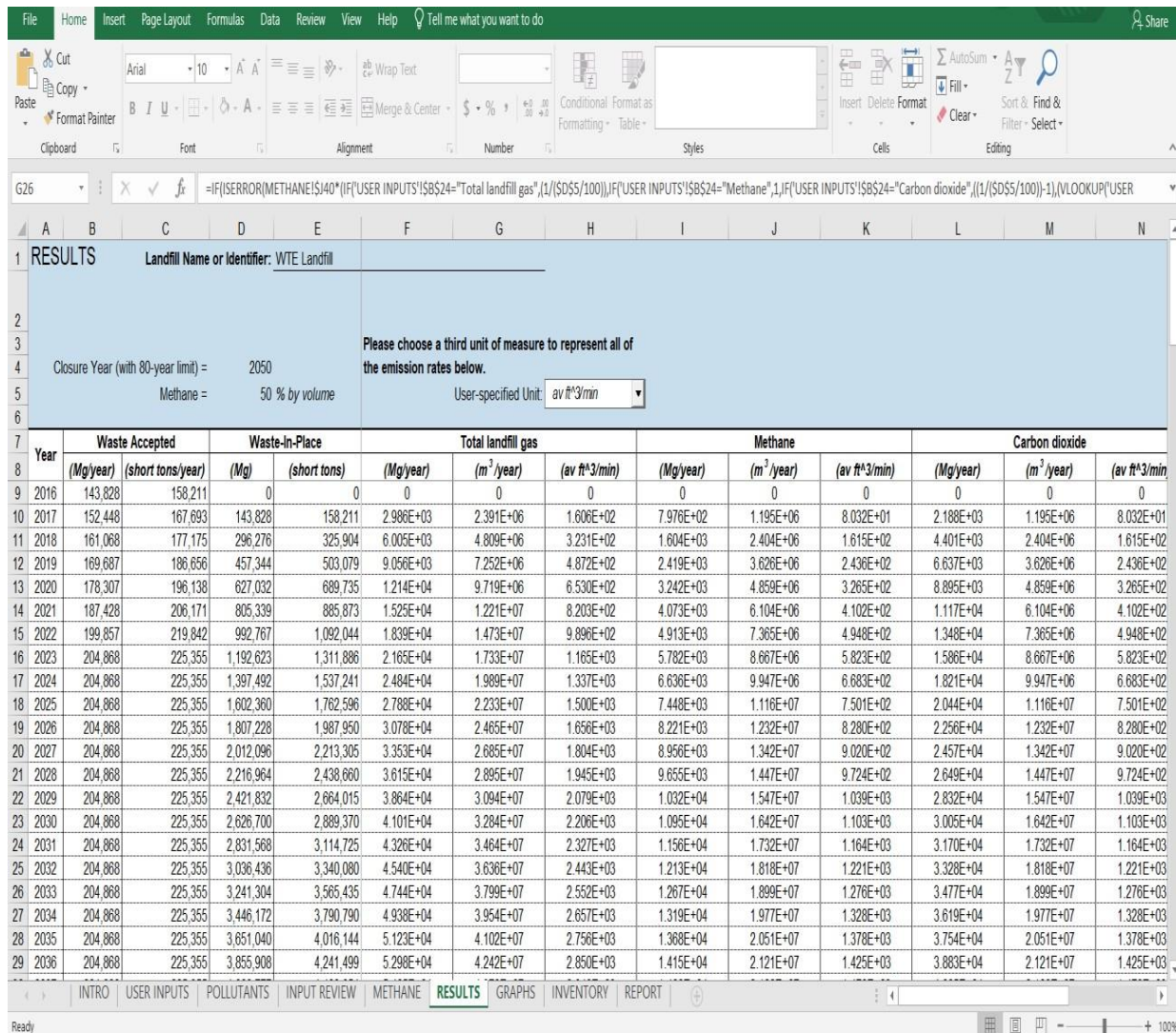


Figure 4.6: Landfill gas generation Per year from LFGTE

The image represents a "Results" section of the LandGEM software, summarizing projected data on waste acceptance, waste-in-place, total landfill gas emissions, methane, and carbon dioxide emissions over a defined timeline (2016–2050). The results provide a breakdown of annual waste accepted (in megagrams and short tons), accumulated waste-in-place, and the corresponding gas emissions in multiple units, such as cubic meters per year, megagrams per year, and volumetric flow rate (m³/min).

From the data, waste acceptance rates increase steadily over the years, contributing to cumulative waste-in-place. This cumulative waste serves as the basis for estimating landfill gas production. The total landfill gas emissions, composed of methane and carbon dioxide, are calculated proportionally based on user-defined

parameters such as methane content (set to 50% in this example). These emissions are presented in detailed numerical formats, demonstrating a clear progression over time, aligned with the waste acceptance trends. This tabular output is crucial for environmental modeling, providing a comprehensive foundation for assessing the environmental impacts of landfills. The methane and carbon dioxide outputs are particularly important for estimating greenhouse gas emissions and designing mitigation strategies such as gas recovery or flaring systems. The results also offer critical data for regulatory reporting and long-term planning for landfill management.

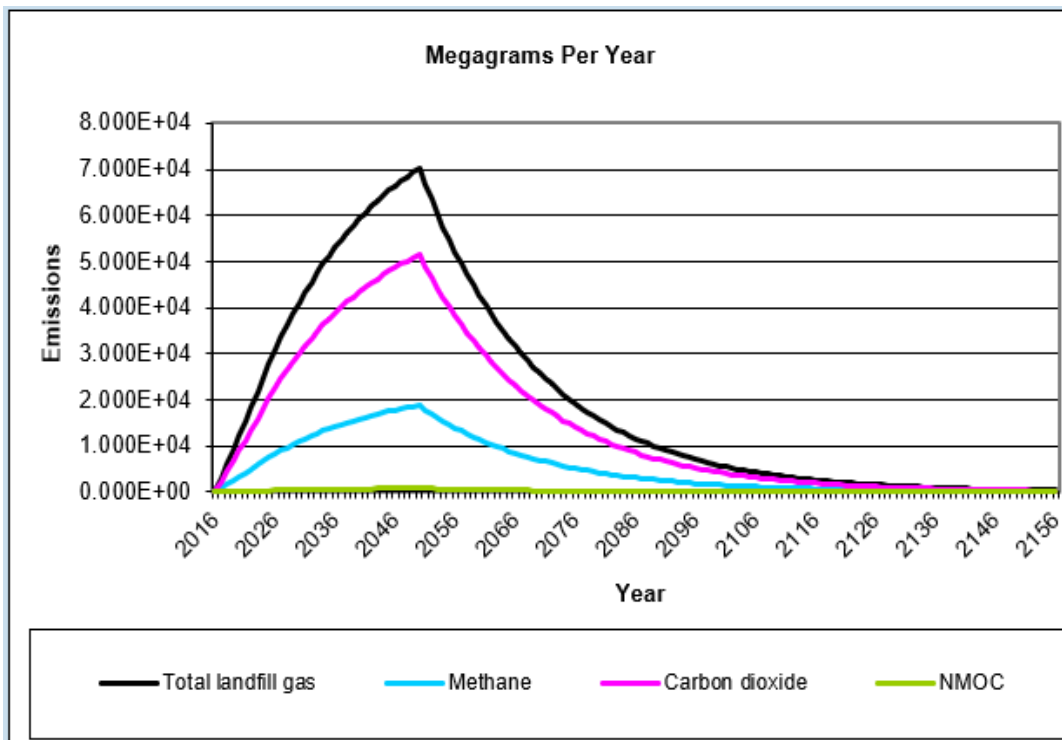


Figure 4.7: Graphical Representation of total Landfill Gas Generated

The black color on the graph represents the total amount of landfill gas generated from LFGTE. The pink color shows the proportion of carbon dioxide in the total landfill gas. Lastly, the light blue color indicates the amount of methane generated from LFGE, which is the primary focus.

4.5 Evaluation of electrical energy potential from the methane collected from LFGTE technology

The electrical energy (kWh/year) that could be obtained from the methane collected from the landfill can be obtained using:

$$E_{p(LFGTE)} = \frac{\varepsilon \times Q_c \times \varphi_1}{\varphi_2} \quad (2)$$

. φ is the conversion factor from MJ to kWh based on the heat content of 2 methane, which is 0.27778. Q_c is the methane collected per annum (m³/year) and can be obtained as follows:

$$Q_c = \lambda \times Q_g \quad (3)$$

Where λ represents % collection efficiency of 75% [23], and Q_g represents the average amount of methane collected per year.[14]

$$Q_g = \frac{\sum_{i=1}^n Q_{CH4}(i)}{n} \quad (4)$$

Here, n is the number of years the methane is collected. Table 4 shows the estimated amount of methane generation from 2017 to 2020 using LandGem software and Figure .

Year	Methane Emission m ³ /year
2017	1.195E+06
2018	2.404E+06
2019	3.626E+06
2020	4.859E+06
2021	6.104E+06
2022	7.365E+06
2023	8.667E+06

Table 4.4 : Methage Generation m³/year From LFGTE

We were able to obtain the result by applying Equation (4).

$$Q_g = \frac{1.195+2.404+3.626+4.859+6.104+7.365+8.667}{7}$$

$$= \frac{4888571 \text{ m}^3}{\text{year}}$$

After substituting the value of Q_g in Equation (3), we can calculate the amount of methane collected in a year.

$$Q_c = (0.75 \times 4888571)$$

$$= \frac{3666428 \text{ m}^3}{\text{year}}$$

To calculate the electrical energy in kWh/year, you need to put the value in Equation(2)

$$E_{p(LFGTE)} = \frac{37.2 \times 3666428 \times 0.33}{0.27778}$$

$$= 162031356 \text{ KWh /year}$$

It is possible to determine the nominal size of the internal combustion engine using this data,

$$G_{PLFG} = \frac{E(PLFG)}{8760 \times CF} \quad (5)$$

$$= \frac{162031356}{8760 \times 0.85}$$

$$= 21760 \text{ Kw}$$

$$\approx 21 \text{ Mw}$$

Where CF is the capacity factor (0.85)[14]

Waste Incineration To Energy

This section provides a step-by-step, comprehensive computation of the amount of electricity produced in Gazipur from MSW. As seen in Figure, there are five primary processes in the computation process.

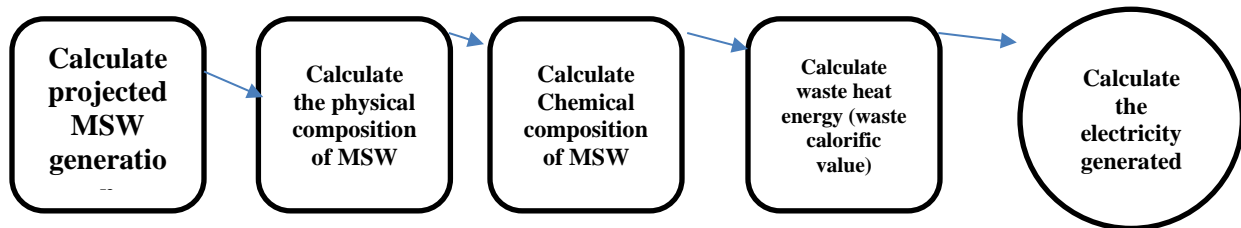


Figure 4.8: Calculation process of electric power generated from MSW [5].

4.6 Evaluation Potential Electric Energy From Incineration Plant using MSW

1. Projected MSW Generation:

Population	2690273 people approx. (2019)
MSW Generation	1004 tons/day approx. (2019) (according to GCC report)
MSW Generation	0.321kg - 0.345kg/capita/day (board bazar)
	0.31kg - 0.5kg/capita/day (kaliakoir)
	0.26kg - 0.30kg/capita/day (kaligonj)
	0.2kg - 0.31kg/capita/day (kapasia)
	0.3kg - 0.33kg/capita/day (sreepur)

BOARD BAZAR	
Yearly Average Collection	93805 TON/YEAR
Daily Average Collection	257 TON/DAY
KALIAKOIR	
Yearly Average Collection	74825 TON/YEAR
Daily Average Collection	205 TON/DAY
KALIGONJ	
Yearly Average Collection	35770 TON/YEAR
Daily Average Collection	98 TON/DAY
KAPASIA	
Yearly Average Collection	50370 TON/YEAR
Daily Average Collection	138 TON/DAY
SREEPUR	
Yearly Average Collection	
Daily Average Collection	49640 TON/YEAR
	136 TON/YEAR

2. MSW Physical Composition Calculation.

The following are some facts and figures on the physical makeup of solid wastes:

1. Determination of the constituent parts of municipal solid wastes.
2. Particle size analysis.
3. The amount of moisture.

4. The solid wastes' density.

First, find the total weight or wet weight of each waste component using the 2019 waste calculation data that is given in Table 6. Second, in accordance with [13], the dry mass of all waste types is calculated using typical moisture content (MC) data.

$$DW = TW - MC * TW \quad (6)$$

Where,

DW- dry weight

TW - Total weight

MC - Moisture content

Table 4.6 shows the percentage weight, wet weight, and moisture content (MC) percentage of each waste component in the 2019 Gazipur MSW composition.

Material	Waste Composition (%)	Total Weight (Tons)	Moisture content (MC) %	Dry Mass (Tons)
Organic	43.32	431.72	70	129.516
Plastic	21.41	216.864	1	214.695
Paper	25.41	255.116	5.5	241.084

Glass	2.66	26.7064	5.87	25.138
Metals	1.86	18.6744	3	18.114
Textiles	2.77	27.8108	3.15	126.934
Rubber and Leather	0.75 Total=100	7.53 Total=1004	3	7.304 Total=762.785

The composition of municipal solid waste (MSW) is analysed in the table, which also shows the dry mass, moisture content, proportions, and total weight of the different waste types. The greatest component (43.32%) is organic waste, which has a high moisture content (70%) and can be used for anaerobic digestion and the production of biogas. Because of their high calorific value and low moisture content, plastics (21.41%) and paper (25.41%) are perfect for thermal processes like pyrolysis and incineration. Metals (1.86%) and glass (2.66%) are more suitable for recycling because of their economic value and non-flammability. Rubber/leather (0.75%) and textiles (2.77%) exhibit promise for recycling and energy recovery. With a dry mass of 762.785 tonnes and a total analysed trash of 1,004 tonnes, the area has a large potential for resource recovery and waste-to-energy conversion. The significance of combining various waste management techniques suited to material properties is emphasised in this composition.

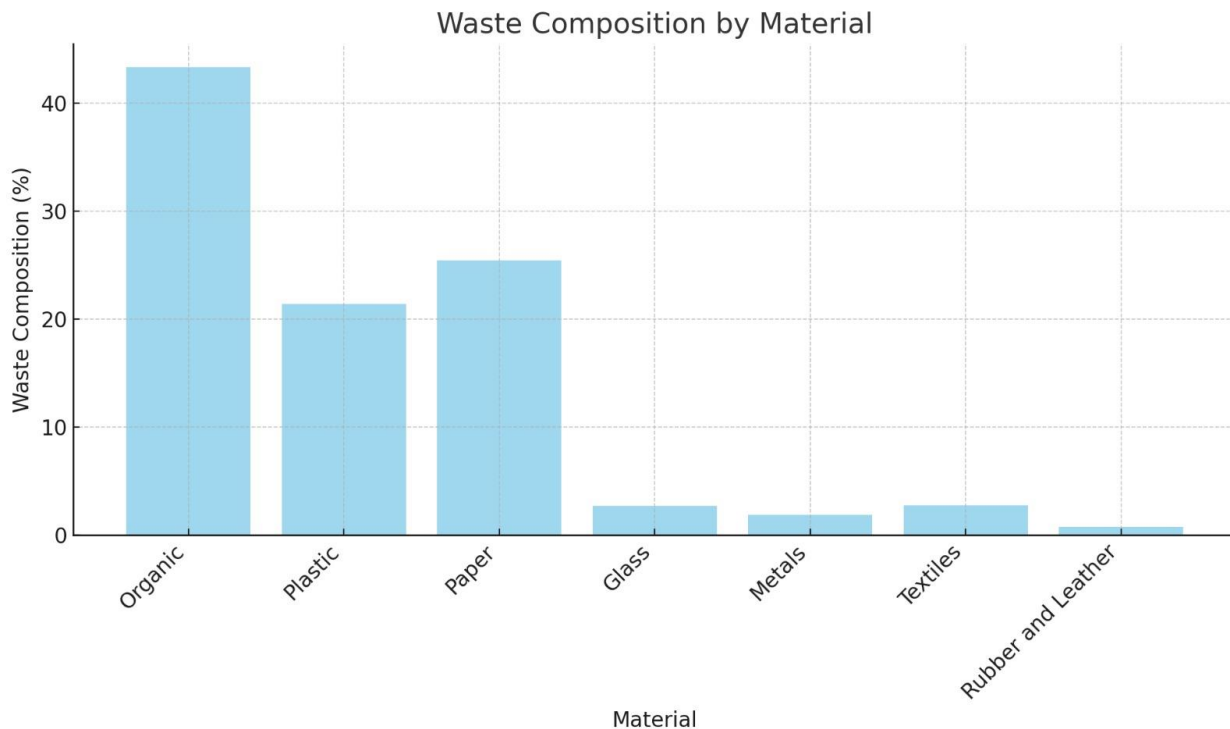


Figure 4.9 shows the total weight of the separated solid trash from all of Dhaka's collection locations.

The waste composition (%) by material is shown in this bar graph. The percentage of each waste category in the overall municipal solid waste stream is shown in the chart:

The majority of waste is organic (43.32%), followed by plastic (21.41%) and paper (25.41%).

The smaller percentages for glass, metals, textiles, and rubber/leather highlight their insignificant role in the composition of garbage as a whole.

The distribution of materials in the waste stream is clearly understood thanks to this visualisation, which is essential for resource recovery plans and waste management planning.

2.MSW Chemical Composition Calculation:

Dry Mass was previously estimated in Section 4.2.1;2. The contents of carbon, hydrogen, oxygen, nitrogen, sulphur, and ash are then determined for each type of waste using a standard table of ultimate analysis of combustible rubbish.

Table 4.7 .Chemical characteristics of Gazipur city's MSW taken into account in this investigation are shown in Table [15].

Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food Waste	48.0	6.4	37.6	2.6	0.4	5
Paper	43.5	6	44	0.3	0.2	6
Cardboard	44.0	5.9	44.6	0.3	0.2	6
Plastic	60.0	7.2	22.8	0	0	10
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10	2	2	0	10
Leather	60.0	8	11.6	10	0.4	10
Yard Waste	47.8	6	38	3.4	0.3	4.5
Wood	49.5	6	42.7	0.2	0.1	1.5
Glass	0.5	0.1	0.4	<0.1	0	98.9
Metals	4.5	0.6	4.3	<0.1	0	90.5
Dirt, ash, etc	26.3	3	2	0.5	0.2	68

(Source: Research Article: Potential Situations to Produce Renewable Electricity in Dhaka and Chittagong City: Municipal Solid Waste to Energy Generation in Bangladesh)

Table 6 shows that the overall waste weight is 1004 tonnes, with the dry waste mass being 762.785 tonnes. The weight of the water in the garbage is then calculated by deducting the weight of the dry waste from the overall weight of the waste [13].

$$\begin{aligned}
 &1004 - 762.785 && (7) \\
 &= 241.215 \text{ Tons } H_2O \\
 &= 241215 \text{ Kg } H_2O
 \end{aligned}$$

Now, we calculate the amount of hydrogen and oxygen in the trash in kilogrammes utilising

$$\frac{TW}{MWt-W} \times MWt - H \tag{8}$$

where

TW = total moisture in kg

MWt-W = molecular Wt of water

MWt-H = molecular Wt of hydrogen

So,

$$= \frac{241215}{8.165} \times 0.907$$

$$= 26795.101 \text{ Kg O}$$

And, MWt-O is the molecular Wt of oxygen.

$$\frac{TW}{MWt-W} \times MWt \quad (9)$$

$$= \frac{241215}{8.165} \times 7.257$$

$$= 214390 \text{ Kg O}$$

Table 4.8: Revised element content.

Element	Revised Dry Mass in Kg	Percent by Dry Mass (%)
Carbon	328691.684	43.091
Hydrogen	41823.501	5.483
Oxygen	177164.444	23.226
Nitrogen	15301.467	2.006

Sulfur	1258.595	0.165
Ash	198560.563	26.031
Total	762785	100

4. Waste Heat Energy of MSW (waste calorific value) calculation:

The heat energy, sometimes referred to as calorific values (higher heating values, or HHV), generated by the solid waste generated across the city of Gazipur must be calculated using Dulong's formula. Dulong's formula is described in equation (10)[13].

$$HE(HHV) = 337C + 1428(H - \frac{O}{8}) + 9S \quad (10)$$

where

-HE = heat energy (kJ/kg)

-C = carbon (%)

- H = hydrogen (%)

- O = oxygen (%)

- S = sulfur (%)

- N = nitrogen (%)

HHV produced by Gazipur city's total garbage is calculated by entering the percent by mass value from Table 8 into Dulong's formula:

$$= (337 \times 43.091) + 1428(5.483 - \frac{23.226}{8}) + (9 \times 0.165)$$

$$= 18207.035 \text{ KJ/Kg}$$

The Dulong equation was once more used to determine the calorific values, taking nitrogen into account in

[13].

$$\begin{aligned} \text{HE(HHV)} &= 337C + 1419(H - 0.125O) + 93S + 23N \quad (11) \\ &= (337 \times 43.091) + 1419(5.483 - 0.125 \times 23.226) + (93 \times 0.165) + (23 \times 2.006) \\ &= 18243.815 \text{ Kj/Kg} \end{aligned}$$

Calculations using equations (10) and (11) produce hardly any different results. Therefore, a lower HHV value will be considered.

The next section will utilise the lower heat value, or lower HHV, for the trash created in Gazipur city, which is 18207.035 Kj/Kg of net heat energy.

5. Calculation of Electricity Generated:

Determining how much power a structure needs requires a number of stages.

First, steam energy, which accounts for 70% of total heat energy, is calculated using the heat generated [5].

An estimated net electric power generated by solid waste is obtained by subtracting heat losses and station service allowance from the steam energy calculation.

Everything is seen in the gallery:

$$\text{SEA} = 70\% \text{ of HE (9)}$$

where the available steam energy is denoted by SEA.

Enter the Lower (HHV) net heat energy value from the preceding section now.

$$\text{SEA} = 0.70 \times 18207.035 = 12744.9245 \text{ Kj/Kg} \quad (9)$$

The turbines, which are connected to generators that generate electricity, are powered by the previously

calculated steam energy. The heat rate (kWh) is the quantity of energy needed to generate one kilowatt-hour of electricity.

$$1KW = 3600 KJ/h$$

Assuming 100% efficiency in energy conversion, the formula above indicates that 3600 kJ of energy are required to produce one unit of electricity. But no energy conversion is 100% efficient; in reality, a power plant needs a conversion efficiency of 31.6% for a heat input of $3600 \div 31.6\% = 11395$ kJ/kWh. Accordingly, 1 kWh of electrical energy requires 11395 kJ of steam energy [13].

$$\begin{aligned} \text{Electricity Power Generation} &= \frac{12744.9245}{11395} \text{ kWh/kg} \\ &= 1.118 \text{ kWh/Kg} \\ &\approx 1.12 \text{ kWh/Kg} \end{aligned}$$

$$\text{Total Weight of Solid Waste(2019)} = 1004000 \text{ Kg/Day}$$

$$\begin{aligned} \text{Total Electric Power generation(TEPG)} &= (1004000 \times 1.12) \text{ kWh/Day} \\ &= 1124480 \text{ kWh/Day} \end{aligned}$$

Here,

$$\begin{aligned} \text{Station Service Allowance(SSA)} &= 6\% \text{ of Total Electric Power generation[13]} \\ &= 67468.8 \end{aligned}$$

$$\text{Uncounted Heat Loss(UHL)} = 5\% \text{ of Total Electric Power generation[13]}$$

$$= 56224$$

Net Electric Power generation = TEPG - (SSA +UHL)[13]

= 1124480 - (67468.8 + 56224) KWh/Day

= 1000787.2 KWh/Day

= 1000.7872 MWh/24h

= 41.69946667 MW

Therefore, by employing WTE to incinerate Gazipur's 1004 tonnes of solid waste per day, or 41.6994667 MW, 1000.7872 MWh/day may be produced.

CHAPTER 5

Evaluation Of The Economic Viability of WTE Technologies

Assessing the financial viability of a waste-to-energy initiative is a crucial step in devising the most suitable investment plan. In this regard, the utilization of the Levelized Cost of Energy (LCOE) and Net Present Value (NPV) is an effective technique to determine the economic feasibility of different technologies for each site. By evaluating the project's LCOE and NPV, businesses can ascertain the financial implications and determine whether the initiative will be profitable in the long run.

5.1 Net Present Value (NPV)

This is the current worth of all of the system's life cycle expenses less the current value of all of its earnings. It is one method of looking at revenue inflows of money and cost outflows of money. For the system to be economically feasible, its value needs to be positive [25]. Here's how to calculate NPV:

$$NPV = \sum_{n=0}^N \frac{F_n}{(1+dr)^n} \quad (10)$$

F_n and dr , respectively, can be found using equations (14) and (15), where N is the total number of years under investigation, dr is the yearly real discount rate, and F_n is the net cash flow rate.

$$F_{n=Rev}(i) - C_{inv}(i) - C_{O \& M}(i) - C_{Tax}(i) \quad (11)$$

Where, R_{ev} is revenue earned from the project, C_{inv} is the total investment cost of the project. $C_{O\&M}$ is operation and maintenance cost, C_{tax} is tax paid on the project, i is the type of technology which could be LFGTE, or INC technologies,

$$d_r = \left(\frac{1+dn}{1+e} \right) - 1 \quad (12)$$

$$d_r = \left(\frac{1+0.12}{1+0.1087} \right) - 1$$

$$d_r = 0.0102$$

Here, dn is the nominal discount rate and e is the inflation rate as furnished by the Central Bank of Bangladesh. Their values as used .

To determine the net cash flow rate F_n in equation (11), the investment cost (C_{inv}) as well as operation and maintenance cost ($CO\&M$) must be evaluated. However, the value of these costs depends on the type of technology to be adopted for the waste-to-energy project. The revenue (Rev) earned from the project can be estimated as:

$$R_{ev}(i) = E_p(i) \times F_d \quad (13)$$

Where, E_p is the total amount of electricity achievable via each of the systems as derived in Equations (2) and (3) for LFGTE and INC technologies, respectively. i is the type of technology, F_d is the cost of selling power in dollars per kWh, and the value is provided in Table 5.1.

Table 5.1 : Economic indices used for the three technologies

Indices	Inflation rate(e)	Nominal discount rate (dn)	Project life time (N) years	(Fd) \$/kwh
Value	10.87%	12%	20	0.045

5.1.1 NPV of Landfill Gas To Energy

5.1.1.1 Determination of Investment Cost (C_{inv}), Operation and Maintenance cost($C_{O\&M}$)

The estimated investment cost for implementing the LFGTE technology is:

$$C_{inv(LFGTE)} = C_v + C_w + C_{kout} + C_{eng} + C_{ICE} \quad (14)$$

All of these costs were calculated in accordance with the Technical Manual for the SAM Biomass Power Generation Model [25].

$$C_v = [Z(ft) - 10(ft)] \times \$85 \times W \quad (15)$$

$$= [50 - 10] \times \$85 \times 1$$

$$= \$3400$$

where z is the depth of the well, and W is the number of wells dug at the dump site. For this landfill gasification Plant design, we assume $z = 50$ feet, $W = 1$.

The cost of installing wellheads and pipes gathering in,

$$C_w = \$1500 \times W \quad (16)$$

= \$150

The cost of installing knockout,

$$C_{kout} = V^{0.6} \times \$4600 \quad (17)$$

$$= (2381)^{0.6} \times \$4600$$

$$= \$488442.52$$

Where, v is the methane flow rate from Figure 6 is 2381 Cubic Feet Per Minute (CFM). The cost of engineering,

$$C_{eng} = \$700 \times W \quad (18)$$

$$C_{eng} = \$1400$$

The cost of Installation of reciprocating internal combustion engine,

$$C_{ICE} = (\$1300 \times S) + 1100000 \quad (19)$$

$$C_{ICE} = (\$1300 \times 22) + 1100000$$

$$C_{ICE} = \$1128600$$

According to Equation (5), the MW-rated capacity of the proposed internal combustion engine (S) is 21MW.

Now, we put all the values from the Equ. (15), Equ. (16), Equ. (17), Equ. (18), Equ. (19) to Equ. (14) to calculate investment cost.

$$C_{inv(LFGTE)} = \$6800 + \$30000 + \$488442.52 + \$1400 + \$1128600$$

$$C_{inv(LFGTE)} = \$1655242.52$$

The operation and maintenance cost of LFGTE technology can be obtained as:

$$C_{O\&M(LFGTE)} = C_{O\&M(LF)} + C_{O\&M(ICE)} \quad (20)$$

Where $C_{O\&M(LF)}$ is the operation and maintenance cost of the landfill site while $C_{O\&M(ICE)}$ is that of the internal combustion engine. The two operation and maintenance costs can be calculated as:

$$C_{O\&M(ICE)} = \$0.025 \times U \quad (21)$$

$$C_{O\&M(ICE)} = \$0.025 \times 162031356$$

$$C_{O\&M(ICE)} = \$4050783.9$$

Where U is the (kWh) produced by the internal combustion engine is found in Equation (2).

$$C_{O\&M(LF)} = \$2600 \times W + \$5100 \quad (22)$$

$$C_{O\&M(LF)} = \$2600 \times 2 + \$5100$$

$$C_{O\&M(LF)} = \$10300$$

Put the value from the Equ. (21) and Equ. (22) in Equ. (20), so the operation and maintenance cost is,

$$C_{O\&M(LFGTE)} = \$4050783.9 + \$10300$$

$$C_{O\&M(LFGTE)} = \$4061083.9$$

Now, by using Equ. (13) The revenue earned from the Landfill Gas to energy project is,

$$R_{ev}(i) = 162031356 \times 0.045$$

$$R_{ev}(i) = \$7291411.02$$

From the Equ. (12) We have $d_r = 0.0102$ now used the Equ. (11) The net cash flow r will be

$$F_{n=R_{ev}}(i) - C_{inv}(i) - C_{O\&M}(i) - C_{Tax}(i)$$

$$F_n = \$7291411.02 - \$1655242.5 - \$4061083.9$$

$$F_n = \$1575084.62$$

Finally, the Net Present value using the Equ. (10) for this project is,

$$NPV = \frac{\$1575084.62}{(1+0.0102)^{20}}$$

$$NPV = \$1285750.22$$

5.1.2 NPV of Waste Incineration to Energy

5.1.2.1. Determination of Investment Cost (C_{inv}), Operation and Maintenance cost (CO&M), also Net Present Value for the Incineration plant:

The following adjustments were made to the Tsilemou and "Panagiotakopoulos" maintenance and operation costs function,

$$C_{inv(INC)} = 61.49 \times M_{F(INC)} \times Q \times R \times S \quad (23)$$

$$C_{O\&M(INC)} = 57.6657.66 \times M_{F(INC)} \times Q \times R \times S \quad (24)$$

$$= \$ 34021419.56$$

Where,

$$M_{F(INC)} = 1004 \times 365 \text{ Tons/Yr } F(INC) \text{ (From Table x.1)}$$

$$= 366460 \text{ Tons/Yr}$$

Now, Calculate Rebates, $R_{ev}(\$) = E_p \times F_d \quad (25)$

$$= 365287328 \times 0.045$$

$$= \$16437929.76$$

Where,

Electricity Generation, $E_p = 1000787.2 \times 365 \text{ Kwh/yr}$

$$= 365287328 \text{ Kwh/Yr}$$

So, Net cash flow,

$$F = R_{ev} - C_{inv} - C_{O\&M} \quad (26)$$

$$= 16437929.76 - 36281253.7 - 34021419.56$$

$$= \$ 86740603.02$$

Finally, Net Present Value for Incineration Plant,[7]

$$\begin{aligned}
 NPV &= \frac{F_n}{(1+d)^{20}} \\
 &= \frac{86740603.02}{(1+0.0181)^{20}} \\
 &= \$ 60591776.82
 \end{aligned}$$

Here, n is the total number of years under study.

5.2 The Levelised Cost of Energy

An additional measurement that can be used to assess the financial viability of a project is the Levelized Cost of Energy (LCOE). The point at which an energy source that is renewable breaks even is the lowest cost of energy produced, expressed in dollars per kilowatt-hour. It can be used as a benchmark to compare the financial viability of various technologies. Equation (31) can be used to determine it for each technology:

$$LCOE(i) = \frac{LCC(i) \times CRF(i)}{E_p(i)} \quad (28)$$

Where LCC is the life cycle cost of the project, CRF is the capital recovery factor, it is the type of technology. The LCC and CRF can be calculated using Equ. (29) and Equ. (30), respectively.

n

$$LCC = C_{inv(i)} + \sum_{n=1}^N \frac{C_{O\&M(i)}}{(1+d_n)^n} \quad (29)$$

$$CRF = \frac{d_n (1+d_n)^N}{(1+d_n)^{N-1}} \quad (30)$$

Where N is the number of years.

5.2.1 LCOE of Landfill Gas to Energy

We already got the value of C from Equ. (14), from Equ. (20) and $inv(LFGTE)$ C $O\&M(LFGTE)$ the value of d from Table 9. n

Now from the Equ. (29) the LLC_{LFGTE} is,

$$LCC = 1655242.52 + \frac{4061083.9}{(1+0.12)^{20}}$$

$$LCC = \$2076242$$

From the Equ. (30) the

$$CRF = \frac{0.12(1+0.12)^{20}}{(1+0.12)^{20}-1}$$

$$CRF=0.1338$$

Finally, the levelized cost of energy for the landfill gas to energy project is

$$LCOE_{LFGTE} = \frac{2076242}{162031356} \times 0.1338$$

$$LCOE_{LFGTE} = \$0.0017$$

$$LCOE_{LFGTE} = \text{BDT } 0.21$$

5.2.2 LCOE of Waste Incineration to Energy:

We already got the value Of $C_{inv(INC)}$, $C_{O\&M(INC)}$ and the value of d_n from the previous section

So, Levelised Cost of Energy is,[7]

$$LCOE_{INC} = \left(\frac{LCC_{INC}}{E_P(INC)} \right) \times CRF_{INC} \quad (13)$$

so,The equation LCC_{INC} is,[7]

$$LCC = C_{inv(INC)} + \sum_{n=1}^N \frac{C_{O\&M(INC)}}{(1+d_n)^n} \quad (14)$$

$$LCC = 36281253.7 + \frac{34021419.56}{(1+0.12)^{20}}$$

$$LCC = \$ 39808144.21$$

So,The equation CRF_{INC} is [7]

$$CRF = \frac{d_n (1+d_n)^N}{(1+d_n)^N - 1} \quad (15)$$

$$CRF = \frac{0.12(1+0.12)^{20}}{(1+0.12)^{20}-1}$$

$$CRF=0.1338$$

Where N is the number of years.

Finally, the levelized cost of energy From Eq(13) for the Waste Incineration to energy project is,[7]

$$LCOE_{INC} = \left(\frac{39808144.21}{365287328} \right) \times 0.1338$$

$$LCOE_{INC} = \$0.01458$$

$$LCOE_{INC} = BDT 1.60$$

Chapter 6

Results & Discussion

Results

The analysis of municipal solid waste (MSW) management in Gazipur City Corporation reveals significant potential for energy generation through waste-to-energy (WTE) technologies, specifically landfill gas-to-energy (LFGTE) and waste incineration. This section presents the results of the economic viability and energy potential of these technologies.

6.1 Waste Composition and Characteristics

Gazipur's MSW composition shows that approximately **54.92%** of the waste is organic, making it well-suited for landfill gas recovery. Plastics (14.7%) and paper (12.6%) contribute to the mixed waste fraction, which can be utilized effectively in waste incineration systems.

6.2 Landfill Gas-to-Energy (LFGTE)

Using the Landfill Gas Emissions Model (LandGEM), methane emissions were projected to increase from **1.19 million cubic meters in 2017 to 8.67 million cubic meters in 2023**. With a methane collection efficiency of 75%, the captured gas could produce approximately **162,031,356 kWh annually**, confirming LFGTE as a viable solution for energy generation.

The economic analysis for LFGTE provided the following:

- **Investment Cost ($C_{inv}(INC)$):** \$1,655,242.52
- **Operation & Maintenance Cost ($C_{o\&m}(INC)$):** \$4,061,083.9/year
- **Revenue (R_{ev}):** \$7,291,411.02/year
- **Net Present Value (NPV):** \$1,285,750.22 over 20 years
- **Levelized Cost of Energy (LCOE):** \$0.0017/kWh (equivalent to BDT 0.21/kWh)

6.3 Waste Incineration

Waste incineration offers a high energy output, converting mixed MSW into energy. With an average input of **1,004 tons/day**, it was estimated to produce **41.7 MW/day** or **1,000.78 MWh/day**, resulting in an annual generation of **365,287,328 kWh**.

The economic analysis for waste incineration provided the following:

- **Investment Cost ($C_{inv}(INC)$):** \$36,281,253.7
- **Operation & Maintenance Cost ($C_{o\&m}(INC)$):** \$34,021,419.56/year
- **Revenue (R_{ev}):** \$16,437,929.76/year
- **Net Present Value (NPV):** \$6,059,177.68 over 20 years
- **Levelized Cost of Energy (LCOE):** \$0.01458/kWh (equivalent to BDT 1.60/kWh)

Discussion

The results highlight the potential of both landfill gas-to-energy (LFGTE) and waste incineration as solutions for Gazipur's waste management and energy generation challenges. The economic and energy analyses provide valuable insights into their feasibility, advantages, and limitations.

6.4 Economic Viability

The LCOE for LFGTE, at \$0.0017/kWh, demonstrates its cost-effectiveness, especially for developing cities like Gazipur. The low investment and operational costs, combined with substantial methane capture, make LFGTE an economically sustainable option. In contrast, the higher LCOE for waste incineration (\$0.01458/kWh) reflects the technology's greater capital and maintenance demands, although it offers higher energy output.

6.5 Environmental Considerations

Both technologies offer significant environmental benefits:

- **LFGTE:** Reduces methane emissions, a potent greenhouse gas, contributing to climate change mitigation.
- **Incineration:** Reduces landfill dependency, minimizing environmental hazards. However, it requires advanced pollution control systems to manage emissions like dioxins and particulates.

6.6 Implementation Challenges

- **Infrastructure Gaps:** The lack of waste segregation and efficient collection systems limits the effectiveness of both technologies.

- **Financial Constraints:** High initial investment for incineration remains a barrier.
- **Public Perception:** Concerns about incineration emissions could lead to resistance from local communities.

6.7 Path Forward

The findings suggest adopting an Integrated Sustainable Waste Management (ISWM) approach, combining LFGTE and incineration technologies to maximize energy recovery and minimize environmental impact.

Chapter 7

Conclusion & Future Recommendations

7.1 Conclusion

The study concludes that Gazipur City Corporation has significant potential to address its waste management and energy challenges through waste-to-energy technologies. The high organic content of MSW makes LFGTE a cost-effective and environmentally friendly solution, while incineration offers a complementary approach with higher energy yields. LFGTE emerges as the preferred solution for immediate implementation due to its low investment cost, lower LCOE, and positive environmental impact. Incineration, though more capital-intensive, provides long-term benefits in reducing waste volume and generating higher energy outputs. The findings underscore the importance of integrating these technologies within Gazipur's waste management framework to achieve sustainability, energy security, and environmental improvement.

7.2 Future Recommendations

Policy Enhancements

- Enforce waste segregation at the source to improve the efficiency of waste-to-energy technologies.
- Offer subsidies or tax incentives for private investments in WTE projects.

Infrastructure Development

- Modernize waste collection systems and establish centralized segregation facilities.
- Create dedicated zones for WTE plants with access to utilities and logistics.

Community Awareness

- Launch campaigns to educate residents about the environmental and economic benefits of WTE technologies.
- Address public concerns about incineration emissions through transparent communication and adherence to emission standards.

Technological Innovation

Pilot advanced waste conversion technologies such as gasification and pyrolysis.

Adopt digital tools for real-time waste monitoring and plant efficiency optimization.

Scaling and Replication

Extend the WTE model to other cities in Bangladesh, learning from Gazipur's experiences.

Seek international collaborations for technical expertise and funding.

By implementing these recommendations, Gazipur can transform its waste management system into a sustainable model, addressing its growing energy demands and environmental concerns while setting an example for other cities to follow.

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APPENDIX A
TURNITIN REPORT

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APPENDIX B

COMPLEX ENGINEERING PROBLEM SOLVING AND ENGINEERING ACTIVITIES

Complex Engineering Problems (P) Solving		
	Attributes	Statement from students
P1	Depth of knowledge required	Addressing municipal solid waste (MSW) challenges involves integrating knowledge from multiple domains: waste composition analysis, energy recovery technologies (e.g., landfill gas-to-energy, incineration), environmental science, thermodynamics, and economic modeling. A deep understanding of these areas is essential to ensure that proposed solutions are both effective and sustainable.
P2	Range of conflicting requirements	Implementing WTE technologies in Gazipur involves balancing multiple conflicting requirements. Economic considerations (cost efficiency, low LCOE) often clash with environmental priorities (emission control, minimal pollution). Additionally, community expectations for clean energy and government policies on waste management create further complexity, requiring engineers to prioritize and reconcile competing needs.
P3	Depth of analysis required	Detailed analyses are critical for decision-making in WTE projects. For instance, methane generation projections using the Landfill Gas Emissions Model (LandGEM) require precise input on MSW properties and decay rates. Similarly, energy output calculations, cost-benefit analyses (e.g., NPV, payback period), and environmental impact assessments (e.g., CO ₂ reduction estimates) demand rigorous computational and analytical skills to derive actionable insights.
P4	Familiarity of issues	Engineers must be intimately familiar with the local context in Gazipur, including the composition of MSW (high organic fraction, low calorific value), limited recycling infrastructure, and socio-economic constraints. They also need to understand cultural attitudes toward waste management and renewable energy adoption, which directly influence project feasibility and public acceptance.

P5	Extent of applicable codes	Compliance with a wide range of standards and regulations is essential for WTE projects. These include national waste management laws (such as those set by the Bangladesh Department of Environment), international environmental protocols (e.g., Kyoto Protocol), and safety standards for energy recovery systems. Knowledge of these codes ensures that engineering solutions are not only effective but also legally and ethically sound.
P6	Extent of stakeholder involvement and conflicting requirements	The success of WTE projects depends on collaboration with diverse stakeholders, including city officials, waste collection contractors, environmentalists, and local residents. Stakeholders often have conflicting priorities, such as cost minimization, environmental protection, and maximizing energy output. Engineers must mediate these conflicts to develop solutions that satisfy as many parties as possible while staying within budgetary and technical constraints.
P7	Interdependence	WTE projects highlight the interdependence between various systems and stakeholders. Waste management systems must align with energy distribution grids, while policies must support infrastructure development. Public acceptance relies on awareness campaigns, and private sector investments depend on favorable economic conditions. This interconnectedness requires engineers to adopt a holistic approach that integrates technical, economic, environmental, and social factors.

Complex Engineering Activities (A)		
	Attributes	Statement from students
A1	Range of resources	The development of WTE solutions requires diverse resources, including technical tools like Landfill Gas Emissions Model (LandGEM), financial investments for high-capital technologies (e.g., incineration plants), and human expertise in areas such as waste management, energy engineering, and environmental science. Moreover, accessing reliable waste composition data and collaborating with stakeholders adds complexity.
A2	Level of interaction	Implementing WTE technologies involves high levels of interaction among various systems and stakeholders. For example, engineers must work with government bodies for regulatory approvals, private waste handlers for consistent waste supply,

		and utility providers for grid integration. Additionally, continuous engagement with the public and environmental groups is crucial to gain support and address societal concerns
A3	Innovation	Addressing waste management challenges in Gazipur demands innovative solutions, such as designing cost-efficient incineration systems that cater to the city's high organic waste content. Similarly, adapting WTE technologies to function under local economic and infrastructural constraints, such as low budgets and limited recycling facilities, requires creative problem-solving and technological advancements
A4	Consequences of society and environment	The environmental and societal impacts of WTE technologies are significant. While these technologies reduce landfill use and mitigate greenhouse gas emissions, they also raise concerns about air pollution from incineration and displacement of waste pickers. Engineers must carefully evaluate these consequences and prioritize sustainable practices that minimize harm while maximizing societal and environmental benefits.
A5	Familiarity	Engineers working on WTE projects must be well-versed in the specific challenges of Gazipur, such as high population density, rapid urbanization, and limited waste segregation practices. Familiarity with local regulatory frameworks, cultural norms, and the socio-economic status of residents is also essential to design solutions that are both practical and widely accepted.