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MANAGING AND GENERATING ELECTRICAL POWER FROM MUNICIPAL SOLID WASTE AFTER METALS AND PLASTICS ARE EXTRACTED FOR RECYCLING IN BAGHDAD IRAQ

Abeer AL-MAMOORI

Master’s Thesis

Supervisor

Asst. Prof. Dr. Engin SANSARCI

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The thesis titled MANAGING AND GENERATING ELECTRICAL POWER FROM MUNICIPAL SOLID WASTE AFTER METALS AND PLASTICS ARE EXTRACTED FOR RECYCLING IN BAGHDAD, IRAQ prepared by ABEER AL-MAMOORI and submitted on 12/04/2023 has been **accepted unanimously** for the degree of Master of Science in Industrial Engineering.

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I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Abeer AL-MAMOORI

Signature

DEDICATION

To that precious soul that left us and we mourn her passing, for those who left a gap in our lives that no one else can fill To my sister To that great person who always wished that her eyes would admit to seeing me on a day like this, To my mother To the one who enlightened my path and was a helping hand for me all my time, To my dear husband.

ABSTRACT

MANAGING AND GENERATING ELECTRICAL POWER FROM MUNICIPAL SOLID WASTE AFTER METALS AND PLASTICS ARE EXTRACTED FOR RECYCLING IN BAGHDAD, IRAQ

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The worsening of solid-waste management in Baghdad poses significant threat to health and environment. The city of Baghdad is split into 13 districts that are dispersed along both sides of the Tigris River. Municipal Solid-waste management is certainly one of Iraq's most challenging environmental challenges. Population development led to a rise in trash generation and a greater burden on infrastructure with limited capacity. After the conflict in 2003, municipal solid waste issues got increasingly severe. Baghdad is disposing of more rubbish in subterranean landfills with little or no regard for human-health and the environment. For the period 2015-2030, the findings indicated that the total expected yearly solid waste is rising. Using the population growth rate of 2.4%, the amount of municipal solid trash in Baghdad in 2030 will be 6,427,733 tons. This rise is anticipated to be around 30 percent. Due to the nation's war circumstances, lack of effective infrastructure, and outdated waste-management system, municipal solid wastes have become one of Iraq's major causes of pollution and environmental problems. To create a sustainable and developed nation, a proper process management system should be implemented to limit municipal solid waste generation and reap the benefits of an organized strategy for the reuse of recyclable materials in other services.

A robust municipal waste management system, including collection, transportation, reuse, reduction, disposal, and life cycle evaluation, is essential to achieve this objective.

Due to the growing growth of municipal solid wastes, this work provides a quick overview of waste management concerns.

The thesis methodically discusses several municipal trash management situations. In addition, the thesis presents a methodical strategy for producing power from solid waste, complete with computation and analysis of different solid waste materials.

Keywords: Generating, Municipal, Waste, Materials, Recycling.

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ABBREVIATIONS

GHGs	:	Green House Gas
MSW	:	Municipal Solid Waste
NSWMP	:	National Solid Waste Management Plan
WMP	:	Waste Management Plan
WTE	:	Waste To Energy
SMM	:	Sustainable Materials Management
GDP	:	Gross Domestic Product
RDF	:	Refuse Derived Fuel
USEPA	:	US Environmental Protection Agency
LHV	:	Lower Heating Value
PAHS	:	Polycyclic Aromatic Hydrocarbons
PVC	:	Polyvinyl Chloride
PTR	:	Polyethye Thylenetc Rephthalate
FP-C	:	Fast Pyrolysis and Combustion
G-PGC	:	Gasification with Plasma Gas Cleaning
G-SC	:	Gasification with Syngas Combustion
USAID	:	United States Agency for International Development
NPV	:	Net Present Value

1. INTRODUCTION

1.1 OVERVIEW

Global population growth, accelerated urbanization, as well as significant technological and economic advancements have all contributed to rising demand for a variety of goods, including wood products, metals, food, plastics, minerals, etc. It is predicted that this consumption pattern will continue to increase, while non-renewable resources like metals and items generated from fossil fuels will replace renewable forestry and agricultural products [1]. The extraction, harvesting, processing, shipping, and waste disposal processes used in the distribution of these resources have also contributed to several environmental concern, most notably the emissions of greenhouse gases (GHGs) [2]. This is really attributed to the energy and/or resources needed throughout different phases of these commodities' life cycles.

Overall, the growing material consumption has resulted in a considerable rise in last waste streams, particularly in the form of municipal solid waste (MSW), and as a result, managing MSW is seen by governments and policy-makers as a key environmental challenge [3]. For instance, around 1.3 billion metric tons of MSW were produced globally in 2012, and by 2025, it is anticipated that this number would increase to nearly 2.2 billion tons [3].

Managing MSW is a significant issue in urban areas all throughout the world, but it affects emerging nations' quickly expanding cities and towns the most. The public's production of MSW is influenced by socioeconomic status (purchasing power), cultural background, location (urban vs. rural), and environmental consciousness [4]. For rural regions and smaller towns, the average quantity of MSW produced daily is between 0.5 and 0.8 kg/cap/day [4], but households in capital territory and big mega-cities like Kuala Lumpur, typically produce between 1.7 and 1.9 kg/cap/day [4].

The Iraqi population exceeds 42 million, making it one of the most populated Arab states. Rapid economic expansion, significant growth in population, rising individual income, and sectarian tensions have exacerbated the country's solid waste management issue [5]. It is projected[6], [7] that Iraq generates about 31,000 tons of waste, more specifically, solid garbage each passing day, with the capita garbage production topping 1.4 kg per day. Baghdad alone generates around 1.5 million tons of solid trash annually [8], [9]. After decades of violence and mismanagement, Iraq's infrastructure for waste treatment is severely degraded, placing a significant burden on the country's rate of trash creation. Due to the absence of efficient garbage management and dumping systems that rely on modern technology, a significant amount of waste in Iraq is disposed of in unregulated landfills. Unfortunately, these sites often show little to no consideration for human health and environmental safety. As a result, landfills in Iraq are plagued by a range of problems, including contamination of surface water, unplanned fires, significant GHG emissions and groundwater pollution [10], [11].

Iraq's National Solid Waste Management Plan (NSWMP) was created in 2007 with the assistance of foreign waste management experts. Consequently, the strategic plan comprises suggestions for improvement and an explanation of decision-making context. Sustainable growth; Development principles; self-sufficiency; Preventative steps; Responsibility of produces; hierarchy of waste; Best feasible environmental choice are the core concepts of strategy development pertaining to waste in Iraq. According to the proposal, Iraq would construct 33 ecologically constructed landfills with a capacity of 600 million m^3 in all 18 governorates by 2027. In addition to landfill construction, the strategy emphasizes on waste gathering, carrying, disposal, recycle, and reuse technologies. Awareness and social training were also considered to provide an educational system that encourages community and individual engagement in trash management in Iraq [8], [12], [13].

In addition to the WMP of Iraqi national, the ministry of environment of IRAQ launched a strong development program of its own in 2008 as part of its attempts to improve Iraq's environmental predicament [14], [15]. Several Iraqi provinces, such as Basra, Anbar, Kirkuk, Thi Qar, Sulaimaniya Erbil, Dohuk, are collaborating with international entities, including EU, USAID, UNICEF, UN Habitat to develop and implement comprehensive SWM master plans [16], [17].

Generating electricity from MSW by extracting metals and plastics for recycling presents a promising solution to the MSW management challenge in Baghdad, Iraq. The city produces approximately 10,000 tons of MSW daily, with most of it currently being disposed of in landfills that are almost at their maximum capacity. Moreover, the traditional disposal method has contributed to environmental and health issues like air and water, air and GHG pollution [18].

The waste-to-energy (WTE) process, which burns MSW to produce steam that drives a turbine for electricity generation, is an effective means of reducing the amount of MSW requiring disposal, conserving resources, and providing energy [19]. Additionally, the WTE process can contribute to reducing the dependence on fossil fuels, which are becoming increasingly scarce and expensive, while supporting the accomplishment of sustainable development objectives [1].

However, the implementation of WTE in Bagdad requires careful planning and consideration of various factors, such as the composition and quality of MSW, the technology and equipment used for the WTE process, and the environmental and social impact of the WTE facility.

1.2 RESEARCH OBJECTIVES

Proper solid waste management is crucial, as it enables recycling, reuse, and energy generation. This thesis analyzes various solid waste management challenges in Baghdad, Iraq, and offers potential solutions. Furthermore, the thesis investigates the amount of energy that can be extracted from SW, as well as the scientific approach to SWM.

The objective of the thesis is to:

a. To analyze the present MSWM scenario in Bagdad, IRAQ.

b. To design a chain model for MSWM including waste collection, segregation, and electricity generation.

c. To investigate the usability of different solid waste materials in real life applications.

d. To calculate electricity generation from solid waste.

e. To compare different electricity generation parameters for various solid waste materials.

1.3 SIGNIFICANCE OF MANAGING AND GENERATING ELECTRICAL POWER FROM MUNICIPAL SOLID WASTE

Household trash, business garbage, and institutional trash all contribute to what is known as MSW. It's a substantial contributor to worldwide greenhouse gas emissions [20] and one of the greatest non-renewable energy sources. To reduce municipal solid waste's negative effects on the environment and guarantee a sustainable future, its proper management and generation into electricity are essential.

The quantity of trash that ends up in landfills may be decreased by using MSW for energy production and management. Methane, a powerful greenhouse gas, is released by landfills [19]. To reduce methane emissions from landfills, MSW can be burned for energy.

Recycling MSW into usable energy is an additional benefit of this method of waste management. MSW may be processed in WTE facilities, which then generate electricity, steam, and/or heat [21]. This method lessens the environmental damage caused by garbage and lessens our dependency on non-renewable energy sources. Furthermore, WTE plants offer an opportunity for local communities to actively participate in waste management and reduce the carbon footprint of their region. Generating electricity from MSW creates job opportunities and contributes to the local economy, critical for the sustainable development of communities [21].

While it may appear unconnected, sustainable materials management (SMM) reports and plans are increasingly including waste management into their coverage of consumption. SMM is concerned with material resource management from the point of resource extraction or harvesting (in industries like mining, forestry, and agriculture) all the way through the stages of production, distribution, consumption, and disposal. As a result, SMM may provide considerable weight to waste management through environmentally friendly methods including source reduction, reuse, energy recovery and recycling. The goal of the "source reduction and reuse" strategy is to decrease garbage in the first place.

Studies suggest that recycling is more prevalent than energy recovery. Previous research revealed that nations with high rates of energy recovery also had substantial recycling rates. However, poorer nations with landfilling as their primary waste management technique had low recycling rates. Additionally, Arafat et al. [23] showed the average energy recovered from different MSW components using various WTE systems, based on electrical energy efficiency. Food wastes are best handled by anaerobic digestion, whereas plastics may be more effectively recycled through gasification. According to Arafat et al. [23], incineration is still a desirable choice among all waste streams since it may be utilized to recover energy from all the waste streams that have been documented. However, other waste kinds including inert, metals, glass, etc., weren't taken into account in that study.

To find better WTE technologies, however, remains a challenging endeavor. Several people are against building WTE facilities because of the dangers of their emissions. [24]. On the other side, several aspects of WTE facilities, such their high prices and difficulty in securing funding, are also unfavourable. However, one of the main issues with WTE facilities is local community opposition, particularly in developing nations with dense populations [25]. Thus, community acceptability is crucial for the effective deployment of any WTE infrastructure. Developed nations have begun to effectively utilize WTE methods for effective waste management after realizing their potential.

Source reduction and reuse are essential components of any waste management plan, involving preventative or coercive measures to optimize energy and resource use in material production upstream processes. Less tree cutting and increased carbon sequestration in forests are achieved by practices such as recycling partly printed sheets in printing and "light weighting" beverage cans to use less metal without sacrificing function. Overall, this approach has benefits such as energy and natural resource conservation, reduced waste toxicity, and cost savings for producers and consumers.

Recycling a specific amount of material can help to reduce environmental emissions from its re-fabrication using virgin inputs. However, effective recycling systems are required to optimize environmental and financial benefits [8]. Recycling provides many advantages, including reducing greenhouse gas and water pollutant emissions, conserving energy, promoting the development of sustainable technologies, providing industry with valuable raw-materials, creating jobs, conserving resources for future generations, and reducing the need for new landfills and incinerators.

In conclusion, managing and generating electrical power from MSW is a crucial step towards mitigating the adverse environmental impact of waste. Waste-to-energy plants can reduce waste sent to landfills, generate clean, renewable energy, and support local communities, providing a sustainable solution to waste management and promoting sustainable development.

1.4 RESEARCH QUESTIONS

a. What are the current methods being used for managing and generating electrical power from MSW in Bagdad, IRAQ, and how effective are they?

b. How does the extraction of metals and plastics for recycling impact the ability to generate electrical power from MSW in Bagdad, IRAQ?

c. What are the environmental and health impacts of managing and generating electrical power from MSW in Bagdad, IRAQ?

d. What are the most cost-effective and efficient technologies available for generating electrical power from MSW in Bagdad, IRAQ, and how can they be implemented?

1.5 ROADMAP

The rest of this dissertation will follow the following format in order to accomplish the aforementioned goal:

Chapter 1: This section provides a synopsis of the study's context, as well as its purpose, aims, importance, and research questions.

Chapter 2: This chapter covers the rigorous literature review with an overview of the waste generation, characteristics and composition, waste to energy options, national waste management plan of Iraq, electricity generation from MSW using different waste treatments.

Chapter 3: This section describes about the whole process of this study from the beginning to end. This chapter outlines the techniques utilized to examine if the methodological operationalization of these techniques for the aforementioned goals was viable. In order to achieve the goals of this research, the tools for method analysis that are now accessible are also briefly presented. The quantitative research method was described here briefly. Figure 1.1 shows the flow outline of the thesis.

Chapter 4: It deals with the analysis and results of the municipal solid waste-to-energy,, major components of incineration plant, incineration plant working approach, electricity generation framework, how much electricity can be generated for different solid waste materials and cost calculation.

Chapter 5: This chapter summarizes and point out the major findings of the current study and suggests some recommendations for future research.

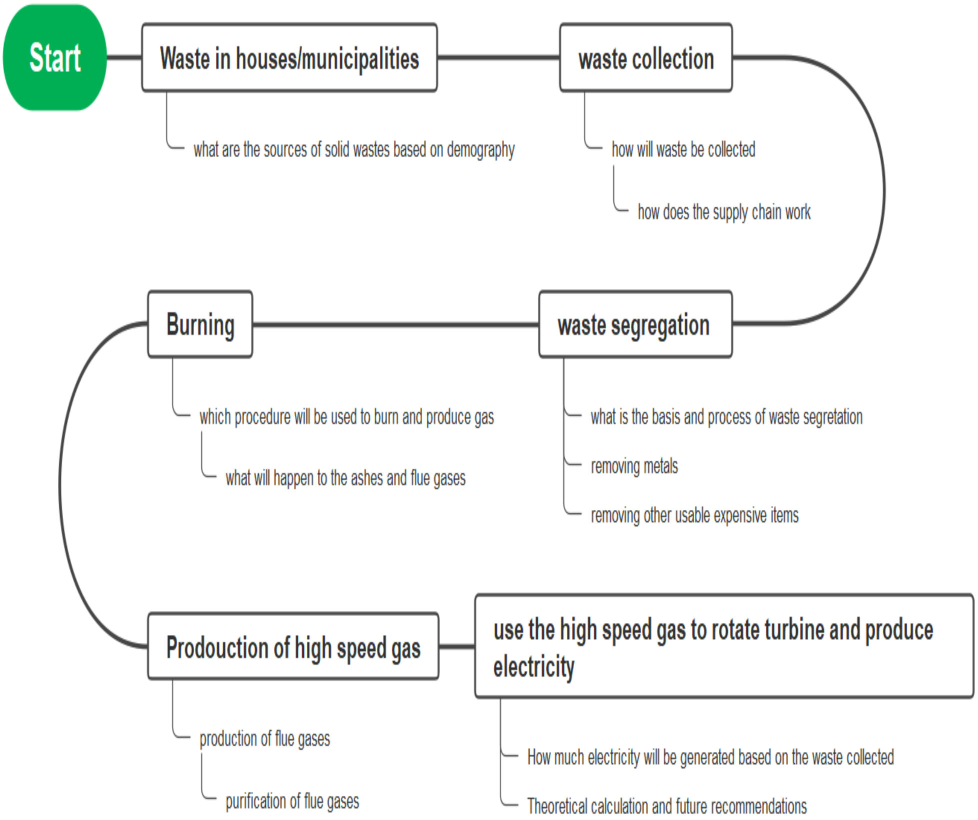

Figure 1.1: Flow Outline of the Work.

2. LITERATURE REVIEW

Iraq is one of the most populated Arab nations, with over 37 million inhabitants. Rapid population expansion, quick economic development, rising personal prosperity, and sectarian strife have all contributed to the emergence of waste management as an urgent concern in the nation. Over 11.3 million tons of MSW are produced yearly in Iraq, with more than 1.5 million tons originating from Baghdad alone [26]. When every individual in the country produces trash at a rate of 1.4 kg per day [26], the total daily trash output is 31,000 tons. Years of mismanagement and conflict have put the country's waste management business in a bind. Most of Iraq's garbage is dumped in unregulated dumps and landfills, endangering the environment and the public's health. Large-scale greenhouse gas emissions, groundwater contamination, and spontaneous fires have all been attributed to Iraq's trash dumps [26].

2.1 WASTE GENERATION, CHARACTERISTICS AND COMPOSITION

Waste production, its characteristics, and its compositions must be well understood before WTE technologies can be selected and implemented. The annual MSW production rate throughout the world was 1.3 billion tonnes in 2012, or an average of 1.2 kg/c/d, according to data undertaken by the World Bank. It is projected that annual MSW output would peak at 2.2 billion tonnes in 2025, and then increase to 4.2 billion tonnes by 2050 [20]. The gross domestic product of a country has a negative correlation with its solid waste output (GDP). The per capita MSW generation rates of several countries are shown against their respective GDPs in Figure 2.1. The International Monetary Fund uses GDP per capita as a criterion for determining which countries are developed and which are developing. Countries are considered developed if they have a per capita GDP of at least $10,000 U.S. Developed countries were defined as having a log10 GDP per capita (US$/year) more than 4, while poor countries were defined as having a value of less than 4.

The pace of MSW generation is closely related to a nation's general level of development. In the majority of the nations, the linear connections between GDP per capita and MSW generation rate per capita (as shown in Fig. 2) were evident. This outcome is in line with the other research that have been published [20].

Another significant finding from Fig. 2.1 is that, compared to other developed nations, some developed nations—including Iceland, Singapore, Japan, Australia, Sweden, and Norway—had lower rates of MSW generation. This may be due to the fact that different nations have different definitions of MSW as well as the fact that some nations, like Japan, have adopted waste reduction policies. According to Thitame et al. [28], the average waste generation rate for affluent nations is between 1.00 and 2.50 kg/c/d and between 0.50 and 1.00 kg/c/d for poor countries.

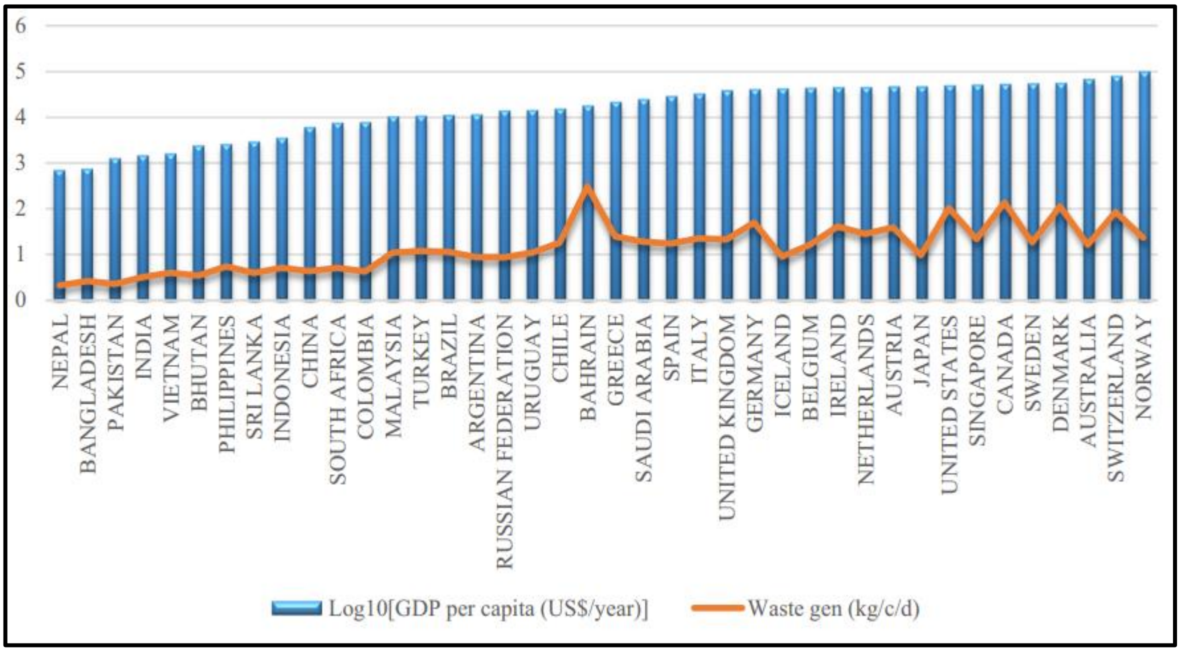

Figure 2.1: Distribution of Waste Generation Rate and GDP of the Different Countries [29].

Knowing the attributes and materials compositions of the produced waste is extremely necessary for an efficient management of the MSW of a city utilizing proper WTE facilities [30]. Both of these variables have a considerable impact on the actual energy output from MSW. moisture content, Particle size, Density and calorific value are a few examples of qualities that are crucial for choosing and establishing a suitable WTE facility [31]. Due to the diverse nature of MSW, waste characteristics and content range greatly across industrialized and developing nations, even even cities in the same nation. The socioeconomic profile, local climate, amount of recycling, frequency of collection, demographics, etc., as well as other factors, such as collection frequency and frequency of collection, determine the physical composition and features of MSW. The waste stream has been separated into six different categories using research previously published on the physical categorization of MSW, including Inert, Kitchen/yard waste, Plastic, Metals, Glass, Paper/cardboard and miscellaneous. The moisture content of MSW in industrialized nations is lower; for instance, it ranges from 20 to 30% in the USA and Europe compared to 50 to 70% in developing nations like China and India [32]. Due to the large proportion of paper and other dry organic wastes, the waste stream of industrialized nations has higher calorific values (2000–4000 kcal/kg) than that of underdeveloped countries (700–1600 kcal/kg) [33]. Table 2.1 displays the calorific values of MSW streams from a few different nations.

Table 2.1: Calorific Values of MSW Streams from a Few Different Nations.

Country	Calorific Value (kJ/kg)	Calorific Value (BTU/lb)
USA	12,000	5,500
UK	9,000 - 10,000	N/A
India	3,000 - 3,500	N/A
Japan	8,000 - 10,000	N/A
China	6,500 - 8,500	N/A
Germany	9,000 - 11,000	N/A
France	8,000 - 9,000	N/A
Canada	8,000 - 10,000	N/A
Australia	9,000 - 10,000	N/A
Brazil	2,000 - 3,000	N/A

High income countries have less decomposable organic waste in their MSW stream and more recyclable materials like plastic, paper, and textiles. In wealthy nations like Japan, the USA, Singapore, and South Korea, the organic content in MSW is around 30% (by weight), but it is above 50% in developing nations like India, Pakistan, Sri Lanka and China [31].

2.2 ELECTRICITY GENERATION FROM MSW USING DIFFERENT WASTE TREATMENTS

Energy and material recovery, followed by residual disposal, are the core goals of any waste management system. There are other factors than energy recovery and safe disposal to consider while deciding on the optimal waste processing technology. Successful operations also demand consideration of local environmental compliance regulations. Thus, it is crucial to use the most efficient waste processing technology available now [34]. Thermal conversion (incineration, pyrolysis, gasification, and energy generation from refuse-derived fuel (RDF)), biological conversion (composting and anaerobic digestion/biomethanation) and landfilling with gas recovery are the three most popular waste conversion processes. Reaction products and MSW treatment approaches are shown in Figure 2.2.

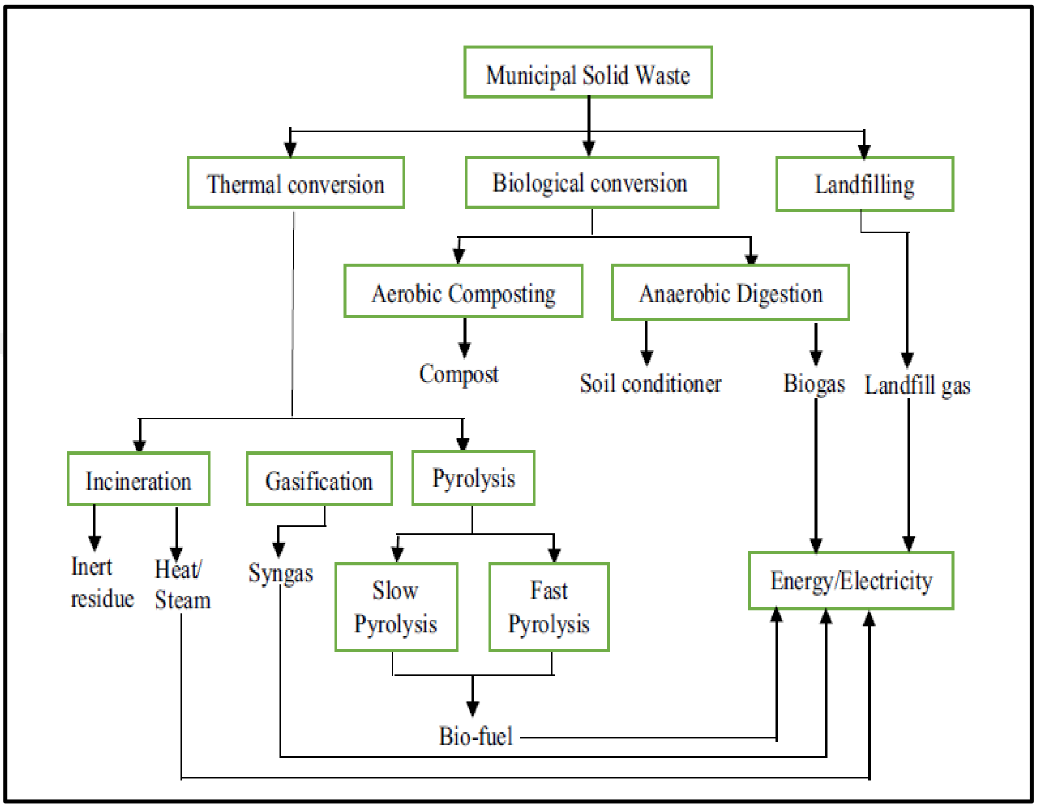

Figure 2.2: Municipal Solid Waste Treatment Techniques and the Products.

2.2.1 Thermal Conversion Technology

The process of turning MSW into usable heat, fuel oil, or gas is called thermal treatment. Waste that is low in moisture and contains a significant amount of inorganic stuff is an ideal candidate for thermal conversion technology. RDF, a combustible material with a high calorific value, is sometimes processed using thermal conversion technology. Crushing and/or pelletizing MSW after recycling and non-combustible materials have been removed yields RDF. The most common form of thermal conversion is incineration [35], which is the controlled burning of garbage at very high temperatures. The two thermal conversion technologies, pyrolysis and gasification, are currently in the research phase because to a lack of MSW characterisation data, poor quality feedstock, and inefficient facility design. Hence, there are inadequate pyrolysis/gasification facilities for MSW processing across the globe [35], [36].

MSW is only one of several waste streams that may be processed at these facilities [37]. Reaction conditions and results typical to thermal treatment procedures are listed in Table 2.2.

Table 2.2: Reaction Conditions and Results Typical to Thermal Treatment Procedures.

Waste Stream	Thermal Treatment Procedure	Temperature (°C)	Residence Time (sec)	Results
Municipal Solid Waste	Incineration	800-1000	1-2 (combustion), 2-4 (post-combustion)	Energy recovery, volume reduction, ash production
Medical Waste	Incineration	850-1200	2 (primary), 4 (secondary)	Volume reduction, pathogen destruction, ash production
Hazardous Waste	Incineration	850-1200	2 (primary), 4 (secondary)	Destruction of hazardous compounds, ash production
Sewage Sludge	Incineration	800-1000	1-2 (combustion), 2-4 (post-combustion)	Energy recovery, volume reduction, ash production
Biomass	Combustion	700-900	2-4	Energy recovery, ash production
Industrial Waste	Pyrolysis	300-900	0.5-2 hours	Gas, oil and char production

The two most distinguishing features of these three thermal treatment methods are the ambient state (in this case, the presence of oxygen) and the operating temperature. The quality of both the finished product and any useful intermediates is determined largely by these two parameters. The operating temperature of thermal processes is heavily influenced by the process design and feedstock materials. In developing countries, MSW is often burned directly without any kind of pre-treatment.

2.2.2 Incineration

Historically, incinerators were not utilized for energy recovery [38], but rather to minimize trash volume and protect people and the environment from dangerous waste. Improvements in technology for reducing air pollution, however, have made incineration a viable waste disposal alternative, especially in developed countries [39], [40]. Due to severe waste disposal restrictions for landfilling, incineration is one of the most prevalent waste disposal techniques in industrialized nations (including the EU, US, and Japan), as mentioned by Scarlat et al. [41]. In 2003, owing to considerable emissions reductions from waste incinerators, the US Environmental Protection Agency (EPA) categorized MSW incineration as a cleaner source of power [42]. In addition to producing heat and/or electricity, incineration may decrease waste mass and volume by as much as 70% and 90%, respectively [43], [44]. Heat from incinerators is occasionally delivered to companies like paper mills in colder nations when district heating is required; in all other circumstances, electricity is created [38]. Bottom and fly ash from incineration facilities may be used in road building and cement manufacture, and in recent years research [46] has highlighted other advantages of incineration, such as the recovery of ferrous and non-ferrous elements. As a result, increased metal recovery technology from incinerator bottom ash will boost public support for WTE facilities [47]. Yet, when utilized for mass burning without pre-treating MSW for energy generation, incineration is regarded the most dependable and cost-effective option for impoverished countries. Incineration may take place in a number of phases, depending on operational factors and the nature of the trash being burnt. The total destruction of all living things and the mineralization of organic materials into harmless by-products are two major benefits of incineration of Waste [38].

The content and features of MSW may vary greatly, therefore taking that into account is crucial when building a WTE plant [48]. Incineration may be utilized for MSW with a low moisture content and combustible non-biodegradable material, and supplementary fuels are occasionally employed. Nevertheless, when the waste's LHV (lower heating value) is 1000 kcal/kg to 1700 kcal/kg or above, their use is unnecessary [43]. [50]. The average calorific value of MSW should be at least 1700 kcal in order for incineration operations with energy recovery to be effective [51]. The International Energy Agency suggests that for realistic incineration operations, the value should be larger than 1900 kcal/kg. The performance of an incinerator may be negatively impacted by the presence of inert waste and high moisture content in municipal solid trash. As a waste stream becomes more wet, its calorific value decreases because of the latent heat of vaporization. In order to get rid of things like excess moisture, inert waste, and harmful components like mercury and chlorine, pre-treatment of trash employing thermal, mechanical, chemical, and biological processes is occasionally required [44]. Average incineration yields are 544 kWh of energy and 180 kg of solid trash per tonne of MSW [52].

Modern MSW incineration plants in developed nations are quite efficient in recovering energy in the form of steam for power production [40]. Because of the lower annual capital cost, lower operational cost, greater daily throughput, better expertise of the operators, and high calorific value of the MSW, incineration was more tempting than other WTE technologies for the cities of industrialized countries [40]. Japan's rubbish incineration technique is well-known across Asia because of the country's stringent rules and limited landfill area. Depending on the country, MSW accounts for anywhere from 35 percent to 80 percent of the total rubbish generated in Western European countries [53]. Similarly, numerous European countries depend significantly on incineration for the purpose of treating municipal rubbish. In the northeastern United States, more than 40 percent of all solid waste is incinerated directly into power. Most developing countries, with the exception of those with rapidly expanding economies, do not find incineration to be economically viable because of (a) its high capital, operating, and maintenance costs; (b) its unfavorable waste characteristics and composition; (c) its lack of technical expertise; and (d) the availability of relatively inexpensive land for waste disposal (such as China, Malaysia, etc.). In contrast, China's MSW incineration has skyrocketed during the previous decade. As of 2013, there were 166 operational incineration plants in China, that burnt 166,000 tonnes per day of MSW to generate electricity, as reported by Li et al. Cheng and Hu [55] claim that municipal waste incineration accounts for a larger share of China's renewable energy output than any other single source. The country is expected to reach 500,000 tonnes/day by 2020. Lombardi et al. (2015) pointed out, however, that China is having problems with MSW incineration because of poor waste feedstock quality, incomplete combustion, and rising levels of air pollution. Garbage in developing countries might be difficult to incinerate due to its high moisture level, varied composition, and low energy content [53].

2.2.3 Electricity Generation Using Pyrolysis and Gasification

Other than incineration technology, pyrolysis and gasification are two fundamental thermochemical conversion processes that may be combined with additional treatments like melting, plasma, distillation, etc. [56], [57]. Despite gasification and pyrolysis technologies' long track record of success in the petrochemical and power industries, their use in large-scale MSW plants is still nascent. The number of commercial-scale facilities using gasification and pyrolysis for waste treatment is still fairly minimal, despite continuous research to develop these technologies for MSW application. Technological improvements that will make these methods more efficient and cost-effective for MSW treatment [58]-[64], assessments of the potential for power generation using these techniques [65]-[67], economic and techno-economic analyses [68], [42], [69], and life cycle assessments [70][71], [72], [57], [73] are the primary focuses of this study.

From gathering feedstock to producing energy, commercial gasification power plants encounter logistical and technical hurdles, as noted in Asadullah's evaluation study [61]. The author discovered that the most challenging aspects of traditional commercial gasification systems were the gasification of feedstocks and the purification of the resulting gas. Consequently, improving feedstock efficiency may be accomplished via the commercialization of updraft or downdraft gasifiers and physical and catalytic tar separation methods.

Nine MSW fractions were pyrolyzed by Zhou et al. [64, 74] to investigate the development of polycyclic aromatic hydrocarbons (PAHs). Pyrolysis of PS resulted in the greatest concentration of PAHs compared to the other fractions studied (PVC, PET, and lignin). In addition, PAH production was higher from plastic wastes than from waste biomass. Hence, the amount and method of PAH release during pyrolysis of various MSW fractions, as well as the concentration of the produced gas and solid, play a role in determining an acceptable feedstock for pyrolysis operations.

Evangelisti et al. [75] contrasted the environmental impacts of conventional MSW treatments with those of landfilling with LFG recovery and burning, which generates electricity. Gasification with plasma gas cleaning (G-Pl), fast pyrolysis and combustion (FP-C), and gasification with syngas combustion were the three cutting-edge MSW treatments studied (G-SC). In addition to improvements in electricity efficiency, they discovered that variations in waste processing (metal recovery in G-Pl vs incineration) and treatment types (thermochemical versus biological) also contributed to varying degrees of environmental effect. The study concluded that G-Pl was the best instance and proposed using it as a starting point for more investigation into high efficiency WTE technology.

Despite the allure of pyrolysis and gasification due to their efficiency and environmental advantages, large-scale MSW plants with high gasification efficiency and high energy recovery have not been built anywhere in the world [108, 110]. This is mostly owing to the stringent feedstock preparation needed for pyrolysis and gasification, and the variability in MSW composition, size, and moisture content that may have an adverse effect on these processes [76]. Also, the efficiency (tar separation) of existing gasifiers and gas cleaning systems must be enhanced before they can be used on a commercial basis.

2.3 NATIONAL WASTE MANAGEMENT PLAN OF IRAQ

In 2007, Iraq created the National Solid Waste Management Plan (NSWMP) to improve the country's waste management system. Producer accountability, polluter pays, a waste management hierarchy, and sustainable development are the plan's four primary components. By 2027, the 33 authorized landfills with a total capacity of 600 million m3 would have been built in all 18 governorates, according to the NSWMP. Waste collection, transportation, disposal, and recycling are all highlighted as critical in the plan's overall strategy. The strategy also places an emphasis on social education as a means of enlisting the support of Iraqi citizens in the effort to improve trash management. The Ministry of Environment of Iraq launched its own development program to better Iraq's environment in 2008. In addition, the international organizations UN Habitat, USAID, UNICEF, and EU are working with the governorates of Kirkuk, Anbar, Basra, Dohuk, Erbil, Sulaimaniya, and Thi Qar in Iraq to create and execute solid waste management master plans in each of these regions.

2.4 GLOBAL PERSPECTIVE

With the help of foreign forces, Kirkuk, Iraq's first city, began a solid-waste management program in 2005. The initiative set out to address the issue of trash disposal in an environmentally responsible manner. Kirkuk's environmentally friendly landfill, constructed in accordance with EPA and EU Landfill Directive requirements, was opened to the public in February 2007 [78], [79], [80].

The first landfill in the world to adhere to international environmental standards was also built with foreign aid in Basra. The goal of UNICEF's solid waste management program in Basra is to increase public understanding of environmental issues by reviving the city's garbage collection infrastructure and establishing recycling "schools" in the informal education setting. An awareness drive for better garbage management is also part of the plan. The program's long-term goals include the installation of a regional treatment and disposal facility and the dispatching of street cleaning personnel. This initiative is part of a larger European Union-funded UNICEF program to improve the quality of Iraq's water and sanitation systems [81, 82, 83, 84].

The European Union funded the creation of UNICEF's solid waste management master plan for the city of Erbil, and the Ministry of Municipalities and Tourism of the Kurdistan Region recently signed a deal with a Canadian corporation to recycle the city's rubbish, which will include the construction of two recycling facilities on the city's eastern and western outskirts. UNICEF also completed a master plan in June 2011 to improve Dohuk Governorate's solid waste management. UNICEF and the EU are helping Iraq reach its environmental sustainability goals for the Millennium Development Goals by developing master plans for solid waste management in the governorates of Anbar, Sulaimaniya, and Thi Qar [85], [86].

The Iraqi government, with the help of national and international organizations like the United Nations Habitat, the United Nations Development Group Iraq Trust Fund, and the United States Agency for International Development (USAID), has modified the waste management plan in response to the information and vision provided by these steps. The Iraqi national waste management plan is expected to improve the situation with solid waste management in the country soon [87].

2.4.1 United States of America (USA)

The quantity of MSW created in the United States of America (USA) in 2013 was over 254.1 million tons, which is more than twice the amount generated in 1960. Nevertheless over this same span, there was a twofold rise in MSW production as measured by kg person/day/1. During the last several decades, there has been a sea shift in the ways that MSW is produced, recycled, composted, and disposed of in the United States. From 1960 to 2013, the percentage of MSW disposed of in landfills dropped from 93% to less than 53% (Fig. 2.3b) [88].

From 5.6 million tons in 1960 (less than 10% of the total MSW created) to 87.6 million tons in 2013 (more than 34% of the total MSW generated), the quantity of MSW recycled has climbed steadily. In 2013, Americans generated around 2 kg of garbage every day, but only about half of it was recycled, another quarter was burned, and the remaining seventeen percent was composted. Hence, in 2013, 52.8 percent, or 134.3 million tons, of all MSW was still sent to landfills (1.05 kg per person each day) [88]. According to the Environmental Protection Agency's (EPA) estimates from July 2011, there were around 560 landfills in the United States using LFG energy recovery. Together, these operations generated around 1730 Megawatt of electricity per year and moved about 310 million cubic feet per day of LFG to end-use applications. In addition, 510 more landfills were found to be excellent candidates for future project development [88].

In order to lessen the environmental impacts of MSW, the United States has achieved great progress in waste monitoring and management via the pursuit of sustainable material management goals. The implementation of environmental laws and regulations in the United States was crucial to these successes. This includes the Resource Conservation and Recovery Act (RCRA), federal landfill regulations, federal composting regulations, and federal regulations for construction and demolition debris (C & D).

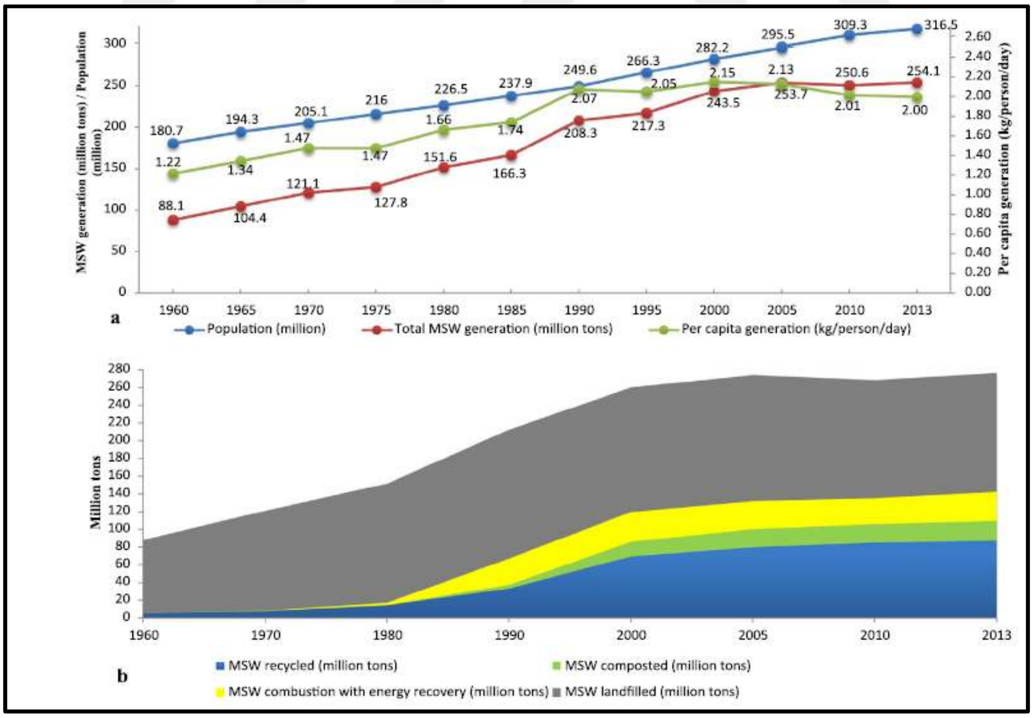

Figure 2.3: (A) Total MSW Generation in the USA (in Million Tons), Per Capita Generation (kg Per Person Per Day), and Population (in Million) (1960–2013). (B) Modifications in the Role of Various MSWs Treatment Alternatives in the USA (1960–2013) [88].

2.4.2 European Union

Figure 2.4a shows the time series for the population of the EU-27 (in millions), the total MSW production (in million tons), and the MSW generation per capita (in kilograms per day). The EU-27, home to 502,16 million people, generated over 241 million tons of MSW in 2013—a rise of 7.1% since 1995 [18]. Nonetheless, MSW production rose only marginally, from 1.30 to 1.32 kg per person per day. From 747 kg per person in Denmark to 272 kg per person in Romania, there was a wide range in MSW production throughout the EU. While these differences may be traced back to differences in waste management and collection methods, they also reflect cultural differences in consumption patterns, standards of living, levels of urbanization, and overall economic well-being among the countries studied.

In recent years, EU members have been moving toward sustainable MSW management [18], as seen by the trends in total MSW treatment from 1995 to 2013 (Fig. 2.4b).

The proportion of MSW sent to landfills in the European Union (EU) in 2013 was less than 31%, which is a significant decrease from the 63.8% reported in 1995. The volume of MSW sent to landfills has dropped because to European waste regulations including Directive 94/62/EC and Directive 1999/31/EC. The first requires all member states to recycle at least half of their commercially produced packaging, while the second limits the percentage of biodegradable municipal trash that may be disposed in landfills to 75% by July 16th, 2006, 50% by July 16th, 2009, and 35% by July 16th, 2016. Directive 94/62/EC requires all member states to implement pre-treatment options other than land filling for the organic fraction of municipal solid waste. These methods include composting, incineration, and mechanical-biological treatment.

In comparison to other treatment methods, the rate of increase in the volume of MSW recycled in the EU was the greatest. The percentage of recycled MSW grew from 11.1% in 1995 to 27.3% in 2013 (from 25 million tons to 66 million tons). Furthermore, the amount of composted MSW rose from 14.2 million tons (6.2% of the total) in 1995 to 36 million tons (14.9%) in 2013. In comparison to the preceding decade, this is a massive growth. In contrast, incineration grew from 32 million tons in 1995 to 62 million tons in 2013, the slowest rate of growth. Nevertheless, it should be noted that the EU does not distinguish between incineration with and without energy recovery in its gathered figures. This is due of inherent challenges in the collection of such information.

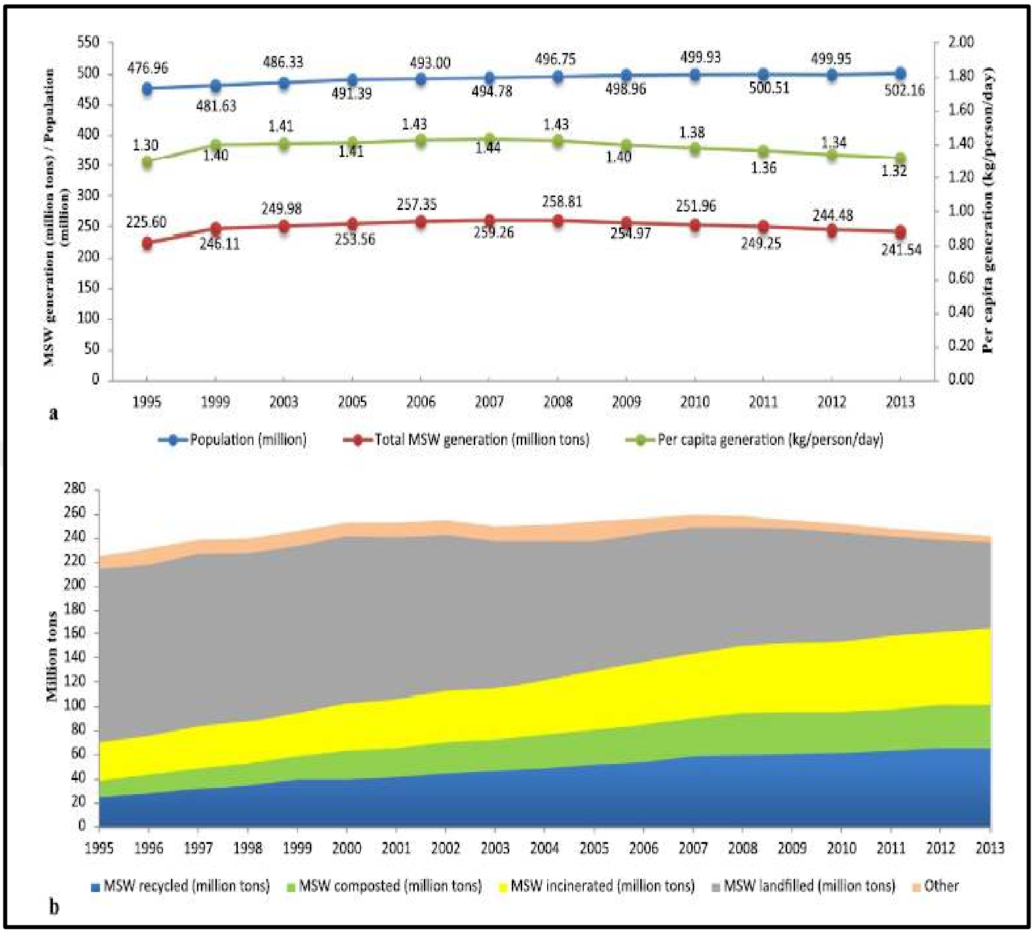

Figure 2.4: (A) Population in the European Union (EU)-27, Total MSW Generation in Million Tons, and MSW Generation Per Capita in Kilograms Per Day (1995–2013). (B) Modifications in the Impact of Various MSWs Treatment Methods in the European Union (EU)-27 (1995–2013) [88].

2.4.3 Asia, Africa, Latin America and the Caribbean (LAC)

As of 2012, Asia has 48 countries and more than 4.2 billion people living on its 30 percent share of Earth's land area [88]. With 54 countries and 1.07 billion people, Africa is the second most populous and biggest continent on Earth (after Asia, which occupies 20.4% of the planet's landmass) [88]. Because of the vastness of these continents and the lack of a centralized database on trash accumulation and disposal, assessing waste management development through time has proven difficult.

The latest research (2012) by the World Bank found that the East Asia and Pacific area generated over 270 million tons of trash yearly, or 0.95 kg per person per day [3] [20]. Around 70% of the trash in this region was produced in China. Over 70 million tons of MSW were generated each year in South Asian countries, or about 0.45 kilogram per day per person [3]. Annual rubbish production in Eastern Europe and Central Asia is at least 93 million tons, or 1.1 kilogram per person each day. Each individual in the Middle East and North Africa generates 1.1 kg of MSW each day [3]. Figure 2.5 shows the MSW production rate per capita across many Asian countries.

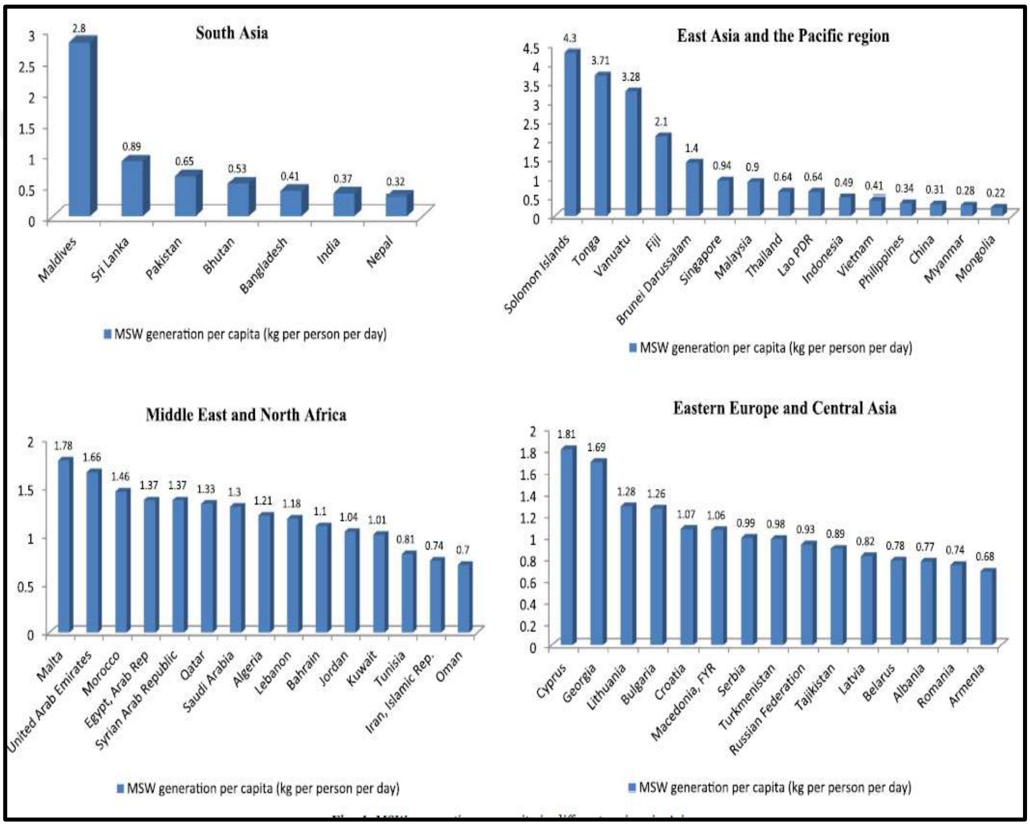

Figure 2.5: MSWs Generation Per Capita in Different Regions in Asia [88].

2.5 ELECTRICITY GENERATION FRAMEWORK

The electricity generation framework refers to the set of policies, regulations, and infrastructure that are in place to produce and distribute electricity to the general public. This framework includes the following elements:

Power generation sources: There are different sources of electricity generation including fossil fuels, nuclear power, hydro power, wind power, solar power, and geothermal power.

Generation and transmission infrastructure: This refers to the power plants, transmission lines, and substations that are used to generate and transmit electricity from the power plants to the distribution network.

Distribution network: This refers to the network of electrical lines, transformers, and other components that are used to distribute electricity from the transmission network to individual customers.

Regulation and policy: Governments play a crucial role in setting and implementing policies and regulations that govern the electricity generation and distribution sector. These policies may include incentives for renewable energy sources, regulations on emissions from power plants, and subsidies for energy-efficient appliances.

Consumer behaviour and energy efficiency: The electricity generation framework also includes initiatives aimed at promoting energy efficiency and reducing energy consumption. This includes programs to encourage households and businesses to adopt energy-efficient technologies and practices.

The electricity generation framework is constantly evolving to reflect new technologies and changing energy policies. The goal is to provide reliable and affordable electricity to the public while minimizing environmental impacts and promoting sustainable energy sources

2.6 ENVIRONMENTAL AND HEALTH ISSUES

Almost all of the research on the potential impacts of WTE plants and other MSWM technologies on climate change has focused on developed countries (UNEP, 2010). Climate change is a worldwide problem that can only be solved with the combined efforts of all governments. Implementing actions with the ability to reduce emissions of greenhouse gases (GHG) and contribute to reducing the effects of climate change caused by the production and consumption of energy derived from conventional sources is of the greatest significance. [90]. A third largest source of anthropogenic methane gas emissions, MSW accounts for a third of all methane released into the environment, according to research by Orval et al. [90]. Three to four percent of all human greenhouse gas emissions come from trash like this, and another eighteen percent come from the waste management industry. No technology has been shown to be capable of detecting methane emission directly from landfills at this time, and this is unlikely to change in the near future. Instead, a variety of theoretical models based on various assumptions are utilized to do this. A method must be put in place to capture methane correctly if it is to be used as an energy source and to safeguard the environment from greenhouse gases with extremely high potential (21 times more strong than CO2). This will enable methane to be used as an energy source while preventing the release of harmful greenhouse gases. This will pave the way for the achievement of both of these goals.

Greenhouse gas emissions might be drastically reduced by recycling and waste reduction [91, 92]. Producing biofuels from MSW (non-recyclable garbage) will have a beneficial effect on global warming, according to studies by Aracil and colleagues [93]. As illustrated in Table 2.3, WTE technology has the potential to contribute to global warming. Wilson et al. (2010) estimate that global greenhouse gas emissions might be reduced by 15-20% if all garbage were managed using the 3Rs (Reduce, Reuse, and Recycle) approach of integrated solid waste management.

Table 2.3: Potential Sources of Greenhouse Gas Emissions from WTE Technology.

Greenhouse Gas Emissions	Description
Carbondioxide (CO2) emissions	The combustion of fossil fuels, such as coal or natural gas, used in WTE facilities to generate energy releases significant amounts of CO2 into the atmosphere.
Methane(CH4) emissions	Landfills are a major source of CH4 emissions from the decomposition of organic waste. WTE technology can divert waste from landfills, reducing CH4 emissions, but combustion of organic waste can also generate CH4 emissions.
Nitrousoxide (N2O) emissions	N2O emissions can result from combustion of nitrogen-containing waste, such as plastics and other synthetic materials.
Particulate matter emissions	WTE facilities can release particulate matter, which can contribute to air pollution and have negative health impacts.
Heavymetal emissions	WTE facilities can release heavy metals, such as lead and mercury, which can have toxic effects on human health and the environment.
Dioxin and furan emissions	WTE facilities can release dioxins and furans, which are highly toxic and persistent pollutants that can have serious health and environmental impacts.

It is predicted that as the world's population grows, so too will the size and population of its major cities. Many residential land-use plans don't even get off the ground without first addressing the issue of solid waste management. Useful trash becomes a by-product of a related consumer good when it is put to productive use. Every day, people generate a huge quantity of trash that must be disposed of at a landfill. The public health and the environment are both negatively affected when communities generate a large amount of solid waste due to incorrect management of landfills. Landfills are the most often used method for getting rid of MSW. Recognizing the kind of garbage is the first stage in the approach to waste management and maintenance; the choice affects the modification and treatment methods, waste density, and recycling [94]-[96]. It's common knowledge that war is terrible for the environment, and it's not only the casualties who suffer. Waste became the leading cause of pollution and ecological concerns since the nation was at war and there was no efficient waste management system in place to recycle and reuse materials. This happened during the turn of the nineteenth century. Since 2003, Iraq's population and economy have grown rapidly, leading to massive increases in garbage. It has been calculated that every day, Iraq produces 31,000 tons of solid trash. The everyday actions of the United States military in Iraq generate around 10 pounds of hazardous trash per soldier. The CENCTOM estimates that there are around 22 active fires in Iraq. Human conflict has always included struggles for the environment. The United Nations Environment Programme reports that war has a major negative impact on ecosystems and natural resource availability. The deterioration of the environment may pose immediate or indirect threats to human well-being, economic security, and physical safety. Garbage that includes potentially toxic substances is improperly disposed of, and the inability to collect trash in separate containers contributes to the degradation of the natural environment. Metals, demolition materials, plastic, paper, glass, fabric, leather, and construction materials are only some of the resources that may be recovered via the process known as "recycling" [97]. MSW is the most diverse kind of rubbish since it includes almost everything produced by people. MSW has four main disposal alternatives, the first of which is commodity recovery, such as the recycling of plastic, paper, and glass (MSW). Other options include burning waste and dumping it in landfills. Second, the combustion of organic materials for energy recovery; third, bioconversion, in which natural components of

MSW) may undergo aerobic oxidation; and fourth, the unrecoverable content of landfills. The effectiveness of the recycling system is proportional to the participation of the general population in sorting recyclable materials. More garbage can be recycled and repurposed if less of it is sent to landfills, and recycling plays a key role in this. Getting rid of trash is vital because properly sorting trash in the onset is a necessary condition for any further progress in waste management to be encouraged. To achieve this goal, several techniques for classification and separation must be used. This is due to the fact that certain materials need compacting to reduce volume, while others may be processed and reused. To ensure that a small number of facilities can effectively process trash from a large territory, it is the responsibility of the local waste management system organization, which comes within the purview of municipalities. The organization is geared primarily at achieving this objective. Regional waste management strategies in Iraq have not been studied as extensively as in other nations. Rather of considering social and environmental consequences, such as waste disposal systems, most studies have concentrated on technological and theoretical hurdles. This is because addressing issues of this kind is more feasible than addressing those of a social or environmental nature. It is crucial to consider all of the necessary factors in order to safeguard natural regions. In order to better comprehend the management system and environmental challenges facing our people today, we will examine all of the primary effects and programs that may be implemented in Iraqi regions in this article. This is all in the name of improving our ability to serve the people. According to data collected and analyzed by Iraq's National Center for Statistics and Analysis, the country's total population rises at 3.03% year. Landfills are places where trash is dumped; in addition to the obvious problem of taking up valuable real estate, they may also have unintended consequences for things like local climate and air quality, as well as the health and happiness of nearby residents and wildlife. Pesticides, fertilizers, the combustion of fossil fuels, and untreated rubbish are all sources of heavy metal pollution, which must be taken seriously since it has the potential to reach levels that are harmful for animals and plants [99].

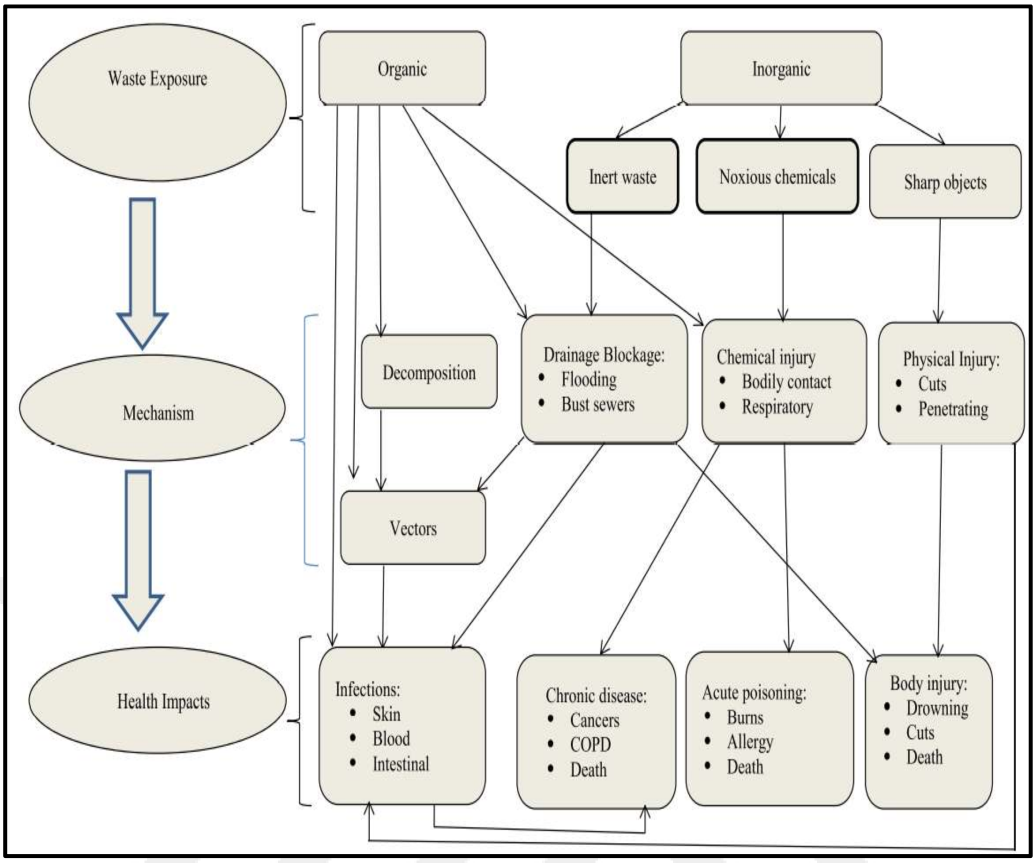

Figure 2.6: An Approach to Comprehending the Connections Between Ineffective Solid Waste Management and Detrimental Health Effects.

Figure 2.5 shows how poor solid waste management can cause different issues for health. Hence it is necessary to find a proper way to deal with the solid waste and get benefit from it.

3. METHODOLOGY

This section covers the different approaches and angles of solid waste management considering the existing scenario of Baghdad city. At first the scenarios are explained and then the methodological approach to produce electricity has been discussed.

3.1 MUNICIPALITIES

Managing municipal garbage is one of the many duties that fall within the purview of local governments. Each municipality has its own cleaning department responsible for managing the collection, transportation, and operation of the transfer stations for all municipal solid trash [100], [101]. The Mayoralty's Municipal Awareness Division and Environmental Division work in each municipality to educate the public about environmental issues, teach residents how to properly dispose of trash, create educational resources—especially for students of all ages—and enlist the support of local mosques, Husseiniyas (Muslim community centers), and other sectors of society [101].

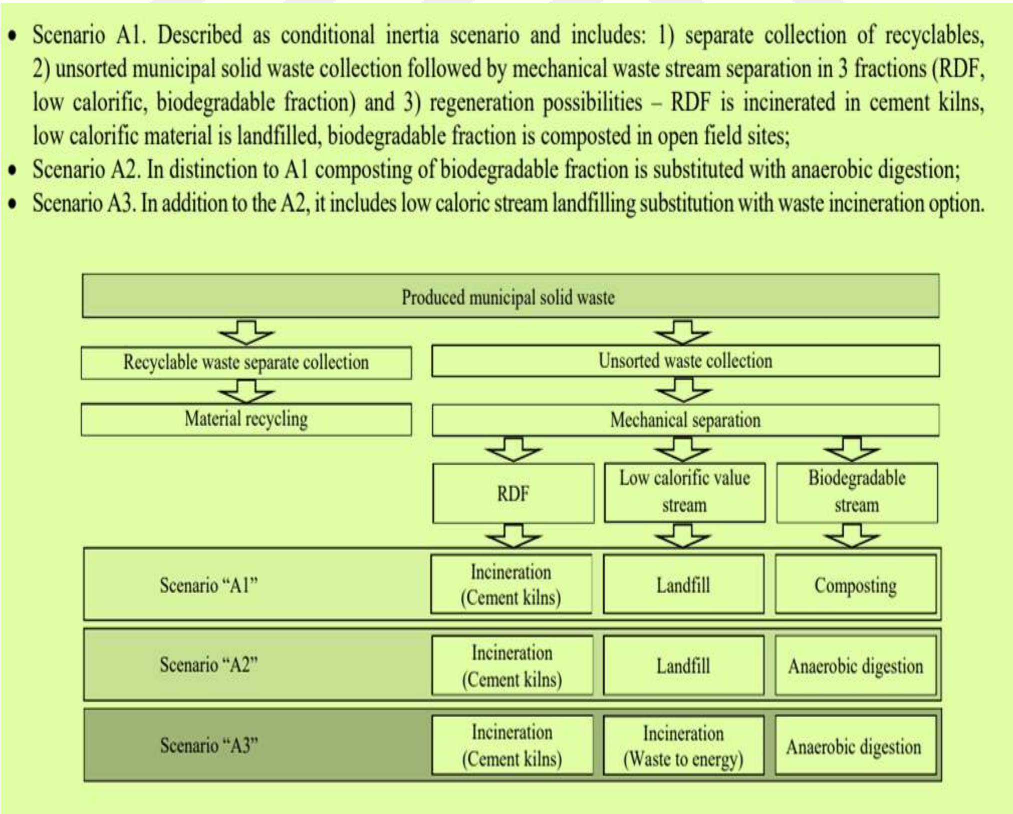

Figure 3.1: Different Ways to Use Municipal Solid Waste.

Figure 3.1 shows different ways of using municipal solid waste. Based on the scenarios a specific way will be suggested in this work.

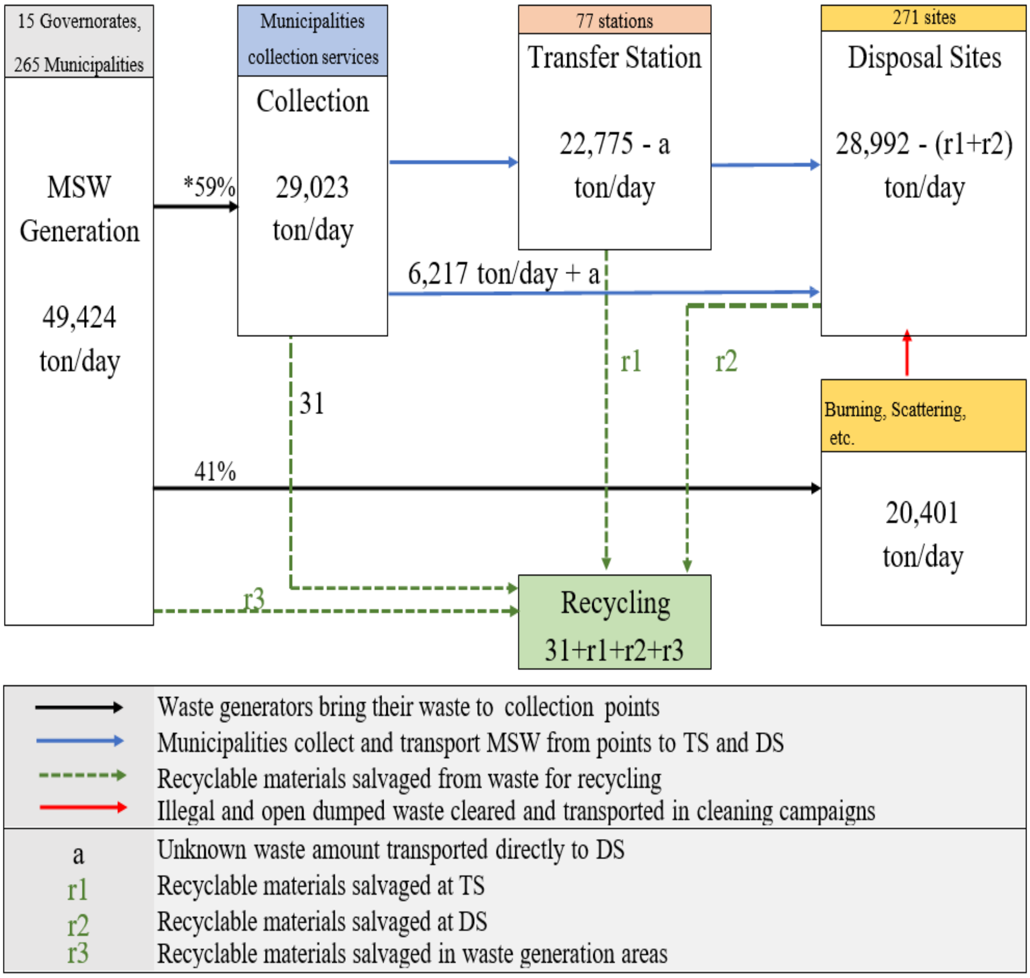

Figure 3.2: Present Solid Waste Management in Iraq.

Figure 3.2 shows us the procedure of collecting solid waste and managing it. As we can see there are four coloured arrows (black, blue, green, red). The figure goes from left to right in a methodological order for solid waste management. At first solid waste is collected from the municipality waste collect points (as shown by black arrows). Then the collected waste is transported from Transfer Stations (TS) to Disposal Sites (DS) as shown by blue arrows. Meanwhile recyclable materials are salvaged from waste for recycling as shown by green dotted arrow lines. The red line shows the illegal and open dumped waste cleared and transported in clearing campaigns. The next section focuses on MSW Management for the City of Baghdad.

3.1.1 Management of Municipal Solid Waste in the City of Baghdad

In 2010, the Ministry of Health and Environment and the Mayoralty of Baghdad created the "Master Plan for MSW Management for the City of Baghdad."

The plan's objectives were:

a. To reduce present and future public health threats

b. To reduce the negative effects of improperly managing solid waste on the environment by prompt collection, safe disposal, and adequate closure and remediation of existing dump sites. to improve the MSW Management system's organizational effectiveness, cost-effectiveness, and clarity of responsibility by hiring people who have received the necessary training. greater aesthetic effect and decreased littering - a tidy city

In order to have proper solid waste management system certain principles are suggested below:

Preventive methodology: Trash creation is ought to be prevented and limited to the fullest extent to ensure natural resource conservation.

The pre-emptive principle: The pre-emptive principle entails a commitment to take required actions to avoid or reduce waste's negative effects on human health and the environment. Particularly dangerous waste materials ought to be avoided.

The polluter pays concept: Waste generators, particularly manufacturers placing items and packaging on the market, should bear the whole cost of collection, transportation, trash treatment, and disposal system.

The closeness and self-sufficiency principle: Ensure a sufficient infrastructure by building a network of integrated and suitable disposal facilities. Waste should not be removed from the region unless there are no other viable alternatives.

Figure 3.3: The Waste Hierarchy.

3.1.2 Municipal Solid Waste Composition

A "Master Plan for MSW Management for the City of Baghdad" was created in 2010 by the Ministry of Health and Environment and the Baghdad Mayoralty.

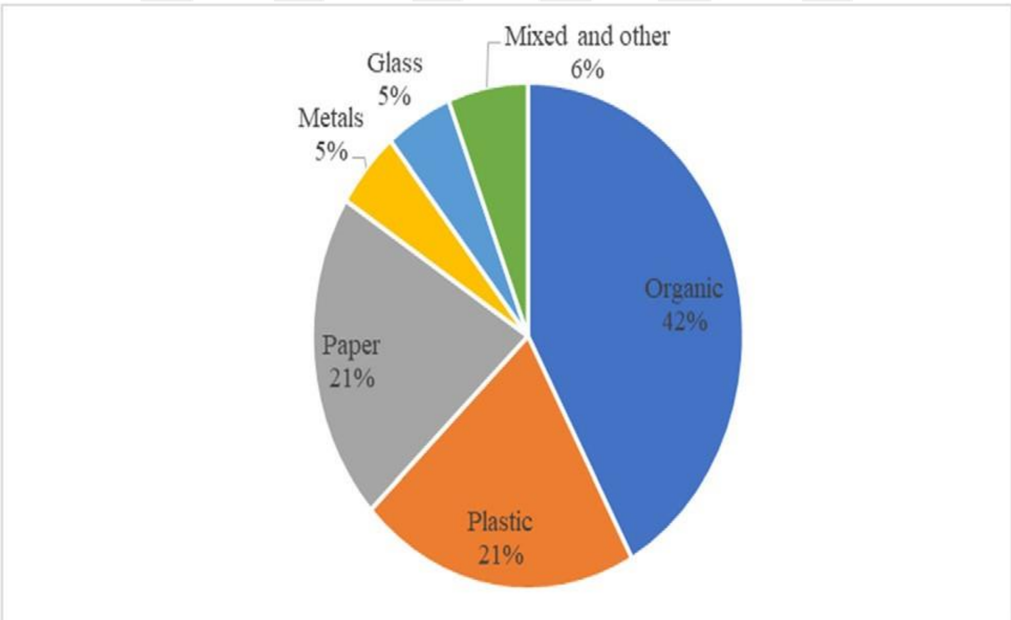

Figure 3.4: Waste Composition in Baghdad Mayoralty.

3.1.3 Collection and Disposal of Waste

As seen in Figure 3.5, garbage is collected utilizing various vehicles at present. There are several types of rubbish in the landfill. Every bit of solid garbage is collected and discarded. There is much room for improvement in these cases. Separation and reuse of resources is an effective strategy for moving ahead.

Figure 3.5: Waste Collection Scenario in Iraq.

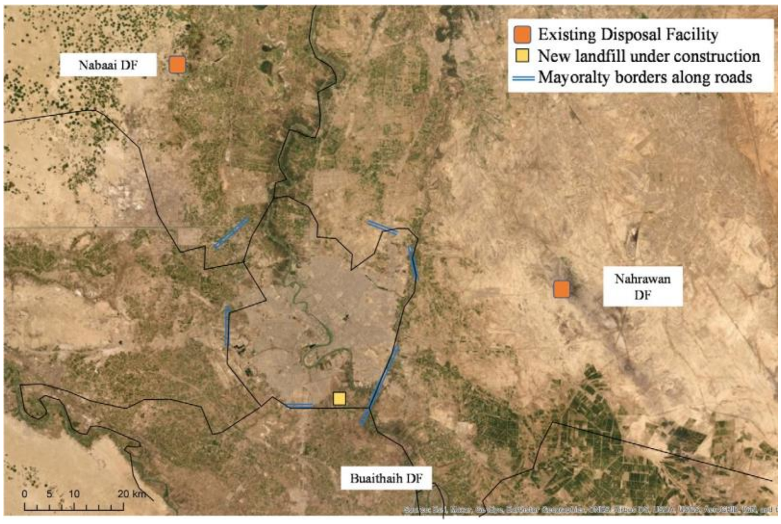

Figure 3.6: Locations of MSW Disposal Facilities Utilized by the Municipality of Baghdad.

3.2 MSW MANAGEMENT FOR BAGDAD CITY

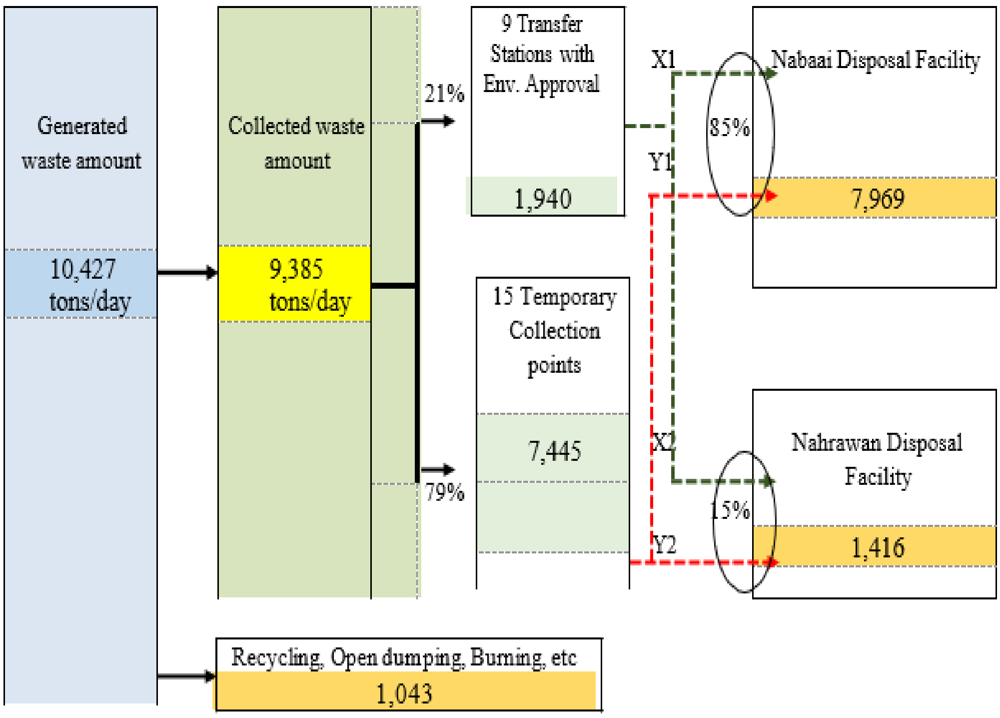

Figure 3.7: MSW Management in Bagdad.

Figure 3.7 shows the MSW flow management for Bagdad. The MSW management system based on previous data is: 90% of the municipal solid garbage produced is collected. 79% of the garbage collected is collected and unloaded at 15 temporary collection sites, and 29% is discharged at official TS. 15% of the garbage was disposed of in Nahrawan DF and 85% in Nabaai DF. Waste pickers at temporary collection locations gather recyclables from a particular collection point. Due to a lack of data, it is impossible to determine the values of X1, X2, Y1, and Y2.

Some key points are explained below:

a. Weighbridges at disposal facilities and transfer stations must be relied upon urgently for reliable data. Baghdad Mayoralty (BM) has acquired weighbridges for the two operational DFs and many of the informal TSs in collaboration with UNICEF after becoming aware of this necessity. The installation of these weighbridges will make it feasible to create MSW flows that are more precise.

b. The aggregate capacity of the nine official transfer stations is 4,500 tons per day (design capacity, 500 tons per station), but only around 43% of that capacity is actually being used. To the fullest extent possible, official transfer stations should be used; temporary and informal transfer stations should not be used. Since some of the uncollected garbage gets recycled, there is evidence that some informal recycling is taking place. BM must comprehend the recycling issue and implement policies to increase recycling.

3.3 WASTE SEGREGATION METHOD

Municipal garbage comprises street wastes, dead animals, market wastes, and abandoned automobiles that come from municipal operations and services. However, the phrase is often used in a broader meaning to include both residential and business garbage.

Methods of Segregation: Segregation or sorting may be performed manually, semi-automatically, or fully-automatically.

Sorting operations by hand:

Manual sorting includes the following:

a. Discarding garbage

b. Spreading garbage manually (with safe precautions)

c. Selecting by hand (with protection) garbage that is physically distinguishable for reuse

d. Collecting and storing the residual garbage

Semi-automatic sorting procedure:

Semi-automated sorting procedures include,

a. Disposal of trash (mechanized).

b. Garbage loading into conveyor belts (mechanized).

c. Manual selection of recyclable garbage from the conveyor line (manual).

d. Collecting, storing, and reloading the leftover trash (mechanized).

Completely automated sorting operation :

Fully-automated sorting procedures include,

a. Disposal of trash.

b. Waste size reduction using shredders and crushers.

c. Separating garbage by size using screening devices.

d. Waste density separation.

e. Magnetic waste separation.

f. Compaction of garbage using balers and crushers.

g. Transfer of trash.

Garbage collection from door to door and the division of trash into biodegradable and non-biodegradable parts at the source would not only reduce the cost of transportation for final disposal but also provide organic waste stock for energy-related activities. Since the amount of rubbish created nowadays presents great issues, it is essential to segregate trash. The aims of sorting are to:

a. Keep recyclable material separately for reuse

b. Ensure that trash that can be treated for material and energy recovery is not combined with unwanted substances.

c. Separate storage of hazardous trash for disposal in hazardous waste landfills or processing

d. To decrease trash and achieve a reduction in ultimate disposal space in landfills.

The following streams of garbage may be separated:

a. Biodegradable Wastes Biodegradable garbage consists of organic waste, such as food scraps, vegetables, fruits, flowers, garden leaves, and paper.

Non-biodegradable waste may be further divided into the following categories :

a. Recyclable trash, including plastics, paper, glass, and metal, etc.

b. Toxic waste: expired medications, paints, chemicals, bulbs, spray cans, containers for fertilizer and pesticides, batteries, and shoe polish.

c. Soiled - hospital waste such as blood- and other bodily fluid-stained clothing. Toxic and filthy garbage must be discarded with extreme caution.

3.4 WASTE SEPARATION

Any object that is to be recycled must first be sorted and processed from raw waste. At the source or at a centralized processing facility, trash may be separated. Individuals practice source-separation, also known as curb-side-separation, by individually collecting papers, different bottles, various cans, trash and depositing them at the curb for gathering later on. Many towns permit the "commingling" of non-paper recyclables. Municipal based garbage collection is usually more expensive than normal rubbish pickup.

Instead of source separation, recyclables and garbage might be separated in centralized mechanical processing facilities. Experiments have shown that ingestion with water particle induced trash and broken glasses reduce quality of recyclables collected from such facilities. Citizens should sort their garbage into a few categories, such as paper, left over magazines, and various other types of wastepaper, different mixed metals, broken glass, and plastics, and junk and other nonrecyclable products. Newspaper, other paper trash, and mixed recyclables are separated from the rest of the rubbish and processed at a centralized material recycling facility, or MRF (called "murf" in waste-management parlance). A technology driven MRF can process around 300 tons of recyclable waste each day.

Recyclable materials are loaded onto a conveyor belt at a typical MRFA oscillating display separates the leftover particles from the shattered glass after a steel separator removes the "tin" cans, that are actually steel cans with a thin coating of tin. Then, the conveyor is sent through an air separator, which distinguishes between lighter aluminum and plastic containers and heavier tumblers. Glassware is usually color-sorted manually, and an eddy-current separator that repels metal from the conveyor belt is used to segregate bottles and cans from polymers.

3.5 REUSE

Crushed glasses may be utilized to make asphalt type pavement. Crushed color-sorted glasses are sent to glass manufacturers as a type of cullet, a critical component in the creation of glass. Aluminum cans and bottles are reprocessed or compacted and transferred to smelters for reuse, while scrap steel-cans are baled, then delivered to steel mills. Aluminum has the highest recycling value while being a small components of the municipal solid -waste system. Because of the large range of polymeric ingredients used in its manufacture, plastic recycling is complex. Blended thermoplastics can only be utilized to produce low-quality items such as "plastic timber."

Aged papers are filtered manually on a moving conveyor belt to filter out corrugated debris and sheets from the paper stream. They are then loosely placed into trucks and sent to paper mills, where they are reused in the production of additional paper. Furthermore, tissues mills acquire mixed paper and corrugated sheet. Even though the procedures of pulping, de-inking, and screening wastepaper are often more costly than those of generating material therefrom virgin cellulose fibres, the demand for recyclable materials has increased as extra processing facilities have indeed been built.

Rubber is periodically recovered from solid waste by shredding, reforming, and remolding it in a process known as revulcanization, although the resultant material is often weaker than the original. Shredded rubber may be used as an element in asphalt pavements and synthetic grass, as well as being sold as outdoor mulch. Tire playgrounds employ used tires as swings and other recreational facilities for children.

Finding applications and acceptable markets is a difficult problem that is associated with reusing and recycling any type of solid waste item. Recycling alone will not enough to meet the ever growing problem that is solid waste disposal with management. There will always be some garbage that is completely useless and must be thrown. Figure 3.8 shows a typical solid waste management cycle.

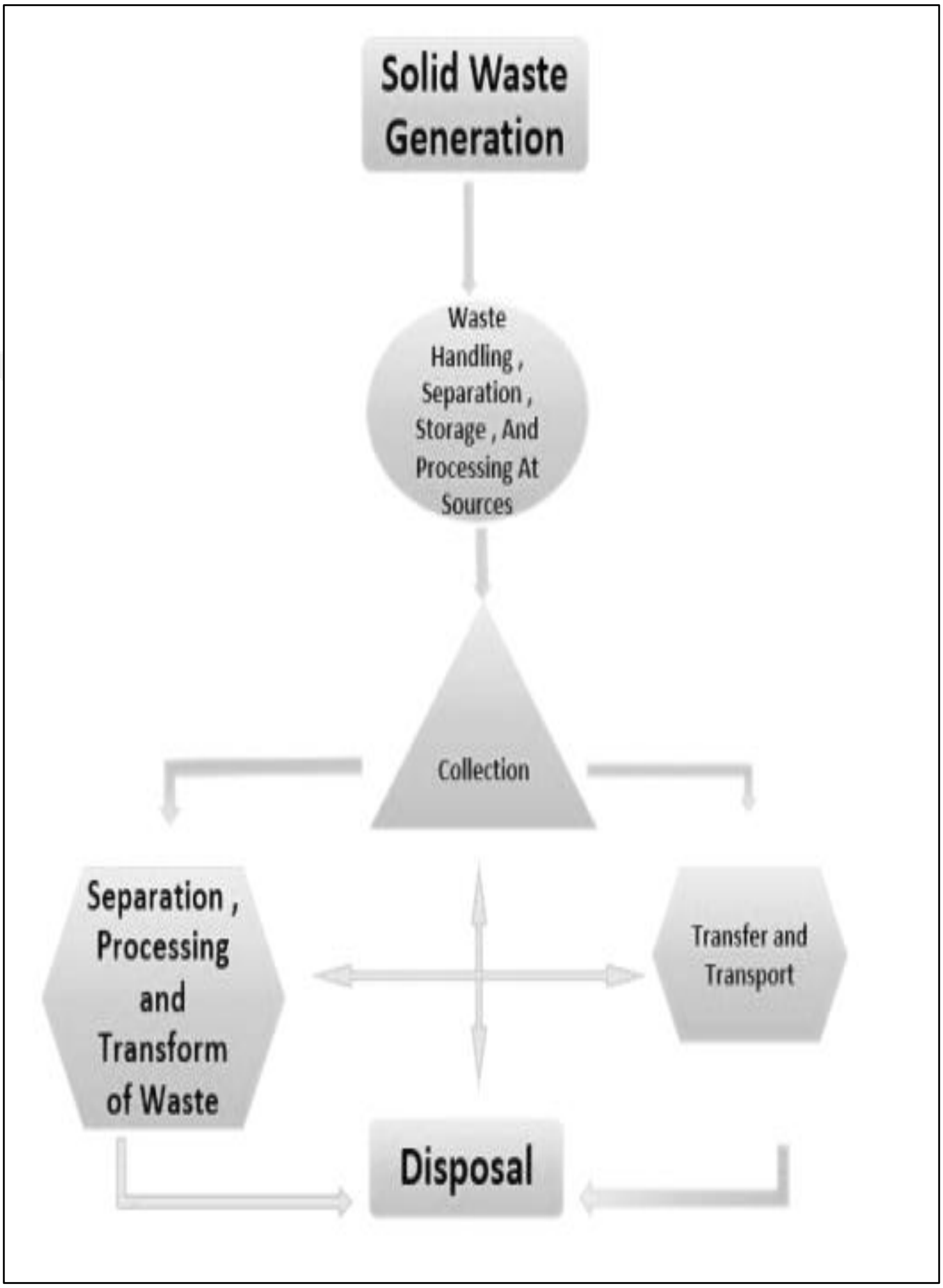

Figure 3.8: Typical Solid Waste Management Cycle.

3.6 SOLID WASTE MATERIALS

Different solid waste materials can be used in different ways. Table 3.1 summarizes some of the ways in which solid waste materials can be used:

Table 3.1: Uses of Solid Waste Materials.

Solid Waste Material	Use
Fly Ash	Filler in asphalt mixes
Slag	Filler in asphalt mixes
Recycled Concrete	Filler in asphalt mixes
Plastics	Manufacture of composite materials, fuel production
Glass	Manufacture of new glass products, abrasives, decorative aggregates
Paper and Cardboard	Recycled paper products, animal bedding, mulch
Metals	Recycling and reuse in manufacturing, scrap metal sales
Electronic Waste	Recycling of metals and other valuable materials, refurbishment of electronics
Food Waste	Composting, production of biofuels and other products
Wood Waste	Landfill cover, energy production, manufacture of particleboard and other

3.6.1 Fly Ash

a byproduct of coal combustion, has several potential uses due to its physical and chemical properties. Some of the most common ways fly ash is utilized include:

3.6.2 Filler in Concrete and Asphalt Mixes

Fly ash has pozzolanic properties, meaning it can react with calcium hydroxide to form stable calcium silicate hydrate, which can improve the durability and strength of concrete and asphalt mixes.

3.6.3 Soil Stabilizationizer

Fly ash can be used to stabilize soil, reducing the plasticity and swelling potential of clay soils and improving the bearing capacity of weak soils.

3.6.4 Waste Stabilization

Fly ash can be used to stabilize and encapsulate hazardous waste, reducing the leachability of toxic substances and improving the safety of landfills.

3.6.5 Agricultural Amendment

Fly ash has been shown to improve soil quality and plant growth in some cases, and can be used as a soil amendment in agriculture.

3.6.6 Waste Water Treatment

Fly ash can be used as a coagulant in waste water treatment, helping to remove suspended solids and heavy metals.

3.6.7 Energy Production

Fly ash can be used as a fuel in certain applications, such as the production of cement and the generation of electricity.

Other materials have similar use as well. The utilization of solid waste materials as alternative fillers in asphalt mixes has been studied in recent years as a way to both reduce waste and improve the properties of asphalt mixes. Some common solid waste materials used as fillers include fly ash, slag, and recycled concrete.

3.6.8 Slag

filler in asphalt mixtures and a byproduct of the steel industry. Slag has been found to boost the toughness and resistance to deformation of asphalt mixtures, among other mechanical qualities.

3.6.9 Recycled Concrete

Crushed debris from demolition sites is a viable filler for asphalt mixtures. Adding recycled concrete to asphalt mixes has been found to increase their stability and longevity while decreasing their need for virgin aggregates.

To fully understand their impacts and maximize their usage, additional study is required into the use of solid waste materials as fillers in asphalt mixes, which is still in its early phases of development. The possible adverse health and environmental effects of using solid waste elements in asphalt mixes also need to be carefully considered.

4. RESULTS AND DISCUSSIONS

The core contribution of the thesis lies in introducing a systematic procedure for SWP for the Baghdad city and the methodological approach of converting solid waste to electricity. Based on the discussions of the previous chapters, this chapter focuses on drawing conclusions and suggesting approaches to manage solid waste and produce electricity.

An elaborate step by step solid waste management plan for the city of Baghdad, IRAQ:

a. Conduction of a waste characterization study :

The first step in solid waste management is to understand the composition of the waste. This information can be collected through a waste characterization study, which involves sorting and weighing waste to determine the proportion of different waste types, such as paper, plastic, metal, etc.

b. Development of a waste reduction program:

Based on the waste characterization study, a waste reduction program can be developed to reduce the amount of waste generated in the city. This program could include public education and awareness campaigns, source reduction efforts, and recycling programs.

c. Implementation of a door-to-door collection program :

A door-to-door collection program should be implemented to increase the efficiency of waste collection and improve the quality of life for the residents of Baghdad. The collection program should prioritize the use of small, efficient vehicles and should be accompanied by a public education campaign to encourage residents to properly sort their waste.

d. Establishment of transfer stations :

Transfer stations should be established to temporarily store waste until it is transported to a final disposal site. The transfer stations should be designed and operated to minimize the generation of leachate and to prevent the release of odors and other pollutants.

e. Construction of a modern landfill :

Baghdad needs a modern landfill to properly manage its waste. The landfill should be designed and constructed to meet international standards for environmental protection, including the implementation of a liner system to prevent contamination of the groundwater, a leachate collection system, and a gas collection system to harness the energy generated by the landfill.

f. Implementation of a recycling program :

A recycling program should be implemented to maximize the recovery of recyclable materials and reduce the amount of waste sent to the landfill. The recycling program should be supported by public education and awareness campaigns and should include the provision of recycling bins and the collection of recyclable materials.

g. Conduction of ongoing monitoring and assessment :

The solid waste management plan should be continuously monitored and assessed to ensure that it is functioning as intended and to identify areas for improvement. This should include regular waste characterization studies, monitoring of the landfill site, and regular evaluations of the recycling program.

This plan is a starting point and should be adapted to meet the specific needs and circumstances of Baghdad. The goal should be to implement a sustainable and environmentally sound solid waste management system that protects the health and well-being of the residents of Baghdad.

Additionally a suggested framework plan for electricity generation is given below:

Solid waste from the city of Baghdad can be used to produce electricity through the process of waste-to-energy (WTE) conversion. The process typically involves the following steps:

a. Collection and transportation :

The solid waste is collected from various locations in the city and transported to a WTE facility.

b. Pre-processing :

The solid waste is sorted and processed to remove any recyclable materials, hazardous waste, and other materials that cannot be burned.

a. Incineration :

The remaining waste is burned in an incinerator, which generates heat.

b. Energy conversion :

The heat generated by the incineration process is used to generate steam, which drives a turbine to produce electricity.

c. Ash disposal :

The ash remaining from the incineration process is stabilized and disposed of in a landfill.

WTE conversion can provide a solution to the growing solid waste problem in Baghdad by reducing the amount of waste in landfills and generating electricity. However, it is important to ensure that the WTE facility operates in an environmentally responsible manner and that emissions are controlled to minimize their impact on human health and the environment. It is important to note that WTE conversion is just one component of a comprehensive solid waste management plan and should be implemented in conjunction with other measures, such as waste reduction, recycling, and proper disposal of non-burnable waste.

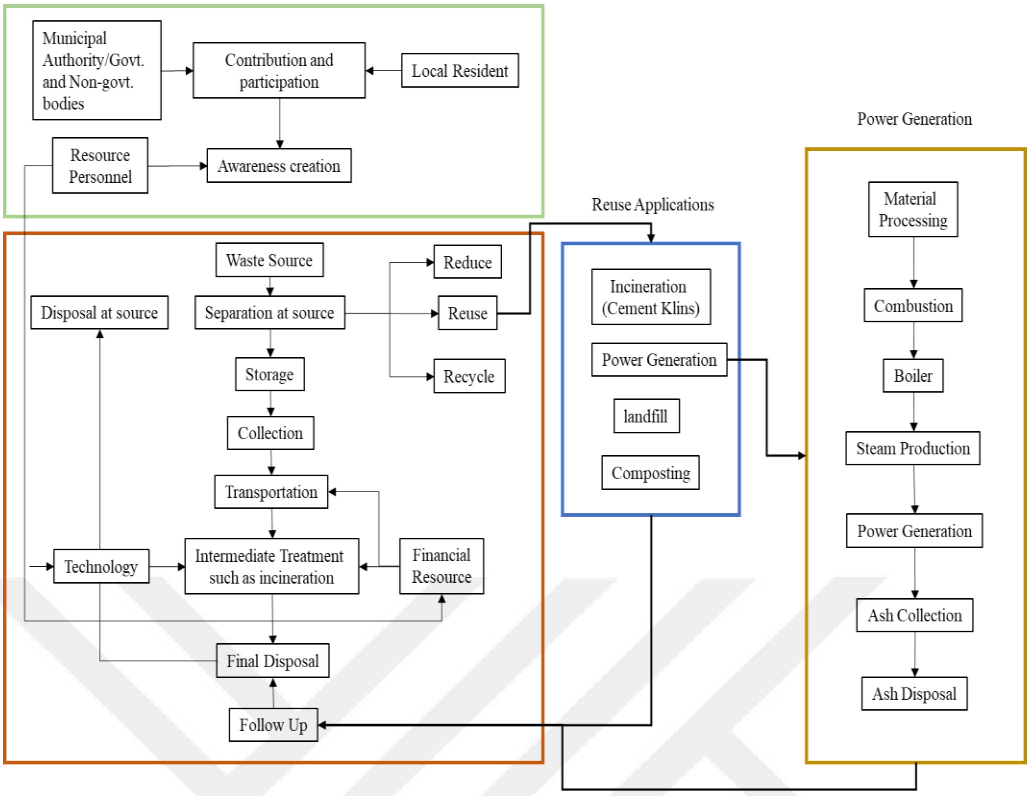

Figure 4.1: Integrated Solid Waste Management and Power Generation Framework.

Figure 4.1 graphically illustrates the entire solid waste management and power generation process. There are total four interrelated zones. The green box indicates different stakeholders of the cause and their contribution. The brown box is a flow process of sequential steps necessary for solid waste management. The blue box shows the applications of reuse solid wastes and finally the yellow box indicates the process of electricity generation. The different aspects are further elaborated in the next sections.

4.1 ASPHALT MIX PRODUCTION FROM SOLID WASTE MATERIALS

The following are the sequential methodological steps to create asphalt mixes from solid waste materials:

a. Characterization of solid waste materials :

This step involves the characterization of the solid waste materials to be used as filler in the asphalt mix. This includes determining the physical and chemical properties of the materials, such as particle size distribution, chemical composition, and mineralogy.

b. Mix design :

The next step is to determine the optimal mix design for the asphalt mix, taking into account the properties of the solid waste materials and the desired properties of the final mix. This typically involves laboratory testing to determine the optimal mix proportions, compaction methods, and curing conditions.

c. Sample preparation :

After determining the mix design, samples of the asphalt mix are prepared using the solid waste materials as filler. This typically involves blending the solid waste materials with the binder (asphalt) and aggregates, and compacting the mix to the desired density.

d. Testing :

The samples are then subjected to a range of laboratory tests to evaluate their mechanical properties, such as stiffness, strength, and deformation resistance. This information is used to determine the suitability of the solid waste materials as filler in the asphalt mix and to optimize the mix design.

e. Field testing :

In some cases, the samples may also be subjected to field testing, such as long-term durability testing and validation of the laboratory results.

f. Implementation :

If the results of the testing are satisfactory, the solid waste materials can be implemented as filler in the asphalt mix for use in road construction and other applications.

It is important to note that these steps should be carried out in accordance with relevant regulations and guidelines, such as those related to the handling and disposal of solid waste materials, and to ensure the safety of workers and the environment.

4.2 MUNICIPAL SOLID WASTE CONVERSION TO ENERGY

MSW-Municipal solid waste, sometimes known as garbage or trash, is burnt to generate steam in a steam generator or boiler, which is then used to power an electric generator turbine in waste-to-energy plants.

MSW is constructed of high density based materials including plastics, paper, yard waste, and wood products. In the US, about 86 pounds of MSW for every 100 pounds of MSW may be burned to generate electricity. Waste-to-energy conversion plants transform about 2,000 pounds of garbage into ash that weighs between three hundred and six hundreed pounds, decreasing waste by about 85%.

In the United States, the most common waste-to-energy technique is the mass-burn system. Untreated municipal solid trash is burned in a large incinerator fitted with a boiler and a generator to create electricity in this way. A less common method isolates non-combustible components from MSW to produce refuse-derived fuel (RDF).

MSW to energy refers to the process of converting non-recyclable waste generated by households, commercial activities, and institutions into a useful form of energy, typically electricity. The basic process involves the following steps:

a. Collection and transportation :

Waste is collected from various sources and transported to a waste-to-energy facility.

b. Processing and sorting :

The waste is sorted and processed to remove recyclables and hazardous waste.

c. Waste treatment :

The remaining waste is treated through a process, such as incineration, gasification, or pyrolysis, to convert it into a fuel.

d. Energy production :

The fuel created from the waste is burned in a combustion chamber to generate heat. This heat is then used to produce steam, which drives a turbine to generate electricity.

e. Pollution control :

The plant's emission control system removes pollutants from the flue gas before it is released into the atmosphere.

The energy generated from waste-to-energy facilities can be used for on-site consumption or fed into the grid for distribution to other users. The goal of MSW-to-energy is to reduce the amount of waste sent to landfills, reduce greenhouse gas emissions, and create a renewable source of energy.

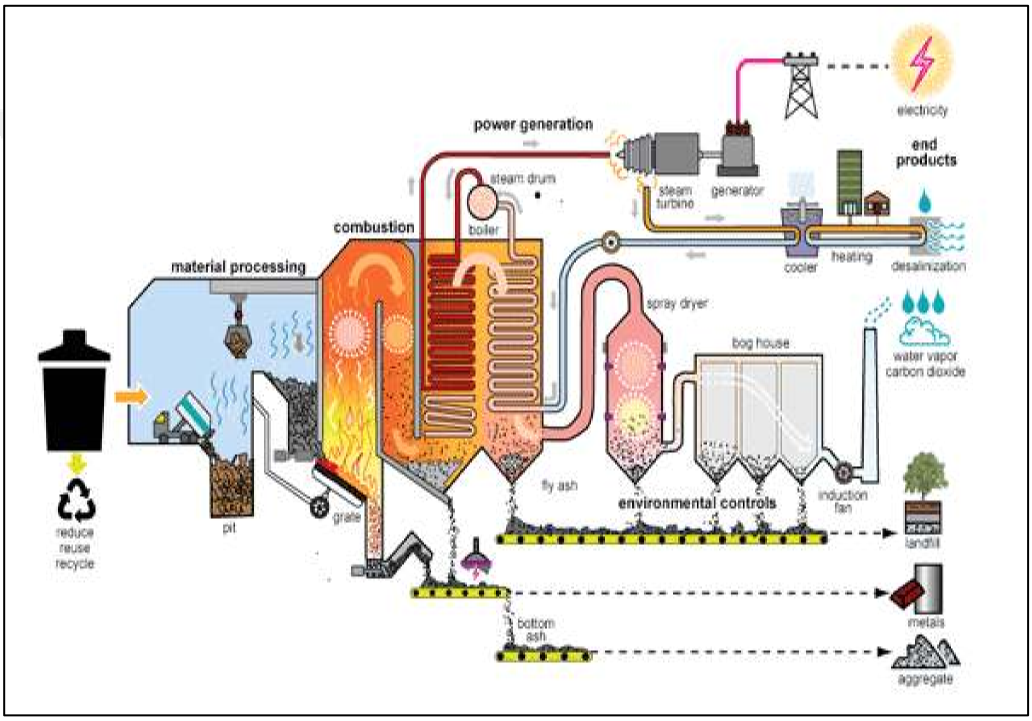

Figure 4.2: Municipal Solid Waste-to-Energy Procedure.

A mass-burn waste-to-energy facility generates power in seven steps as presented in Figure 4.2:

a. Garbage collecting trucks drop trash in a large hole.

b. A crane's enormous claw seizes rubbish and puts the trash in a combustion facility chamber.

c. Solid waste-based fuel is burned to generate heat.

d. Next, heat helps convert water to steam in the steam generator or boiler.

e. The blades of an electricity-generating turbine generator are spun by high-pressure steam.

f. Controlling air pollution involves removing impurities from flue gas before the flue gas is discharged.

g. Finally, ash gets collected.

There are several techniques for converting garbage to energy. RDF facilities process MSW before direct combustion (MSW). Pre-combustion processing varies each facility, but commonly includes shredding municipal solid trash and removing metals and other bulky materials. Municipal waste energy handles two problems at once: garbage and energy needs. Waste-to-energy plants might be highly cost-effective and generate no pollutants or carbon dioxide, which would hasten global warming. MSW is lucrative not just via collection fees, but also through developing profit-generating byproducts. It is critical to highlight that landfills are outlawed in Germany, and all garbage is creatively reused.

Biomass energy is a clean source of energy in Brazil. Over one million people work in the biomass industry, which provides for 27% of the nation's energy output. Almost 90% of biomass utilized to produce power comes from waste or leftover fuels.

In terms of biomass consumption, India stands second in the world (MNRE). Landfills may be used to harvest biomass. Methane gas is created as garbage decomposes. Methane is the main component of natural gas. The landfills are outfitted with pipes that collect methane gas. It is then used to create electricity in power plants. This is referred to as landfill gas.

4.3 MAJOR COMPONENTS OF INCINERATION PLANT

a. Waste collection with handling system.

b. Utilization of heat with recovery (boiler).

c. Control system for environmental safety (air pollution control).

d. Handling system for combustion solid residue.

4.4 INCINERATION PLANT WORKING APPROACH

Similar in comparison to how conventional power-plants use coal based fuels, oils, or natural gases as fuel, Waste-to-Energy (WTE) converts garbage into energy. Steam generated by burning fuel turns a turbine, which generates electricity. For every ton of garbage that isn't burned, the procedure may cut down on carbon dioxide emissions by a ton.

The methodological flow process for incineration, as presented in Figure 4.2 can be summarized as follows:

a. Waste Collection: Waste is collected and transported to the incineration facility.

b. Waste Storage: The waste is temporarily stored until it is processed through the incinerator.

c. Waste Preparation: The waste is sorted and pre-treated to remove hazardous materials, recyclable items, and to reduce its size for easier handling and processing.

d. Fuel Addition: Fuels such as natural gas, propane, or oil may be added to the waste to increase its heating value.

e. Combustion: The waste is burned in the incinerator at high temperatures, typically above 850°C, to break down the organic matter into simple compounds.

f. Emissions Control: The incineration process generates various pollutants, including particulate matter, dioxins, and heavy metals. To control these emissions, the exhaust gases are typically passed through scrubbers, filters, and other treatment systems before being released into the atmosphere.

g. Ash Management: The remaining ash and residue are collected and managed as hazardous waste, either being stored on-site or transported to a landfill for disposal.

h. Monitoring and Record Keeping: Incineration facilities must regularly monitor emissions and other environmental parameters to ensure they comply with regulatory requirements, and keep records of their operations and waste management practices.

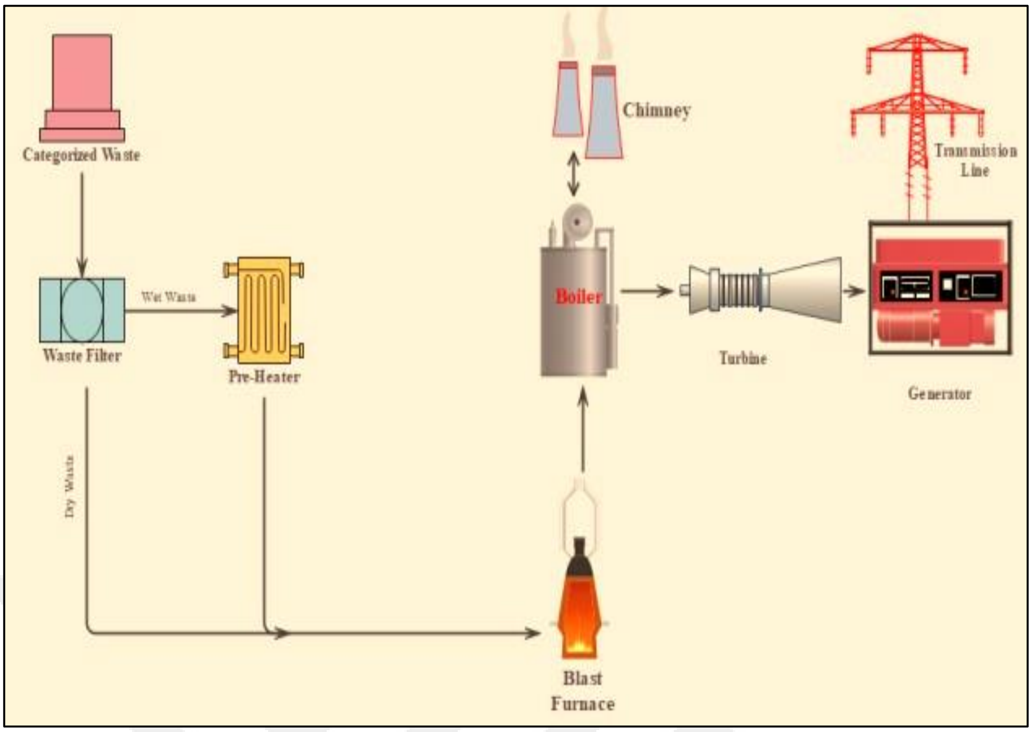

Figure 4.3: Methodological Flow Process for Incineration.

4.5 ELECTRICITY GENERATION FRAMEWORK

Categorization of Waste: The garbage classification area receives each of the items that have been gathered across the region. Wet and dry waste are the two primary categories in this division. Two separate types of waste exit this part at various locations; the wet waste goes via the pre-heater section, which lowers its moisture content. Most of the regularly discarded garbage is used in this way to lower their relative humidity.

Blast Furnace and Pre-Heater: Even before solid waste reaches the smelter, it is heated using a pre-heater. The operation' heating step is completed in a combustion process. Waste material is burned in this portion to boost the temperature necessary to heat the boiler and generate steam.

Boiler: In the boiler portion, heated water is produced using the blast furnace's generated heat. Steam is then generated. Using a fast-moving flow of water, steam, gas, air, or another fluid, a wheel or rotor that is often equipped with vanes is made to rotate in a turbine is a machine that generates uninterrupted power supply. It connects to a generator at the very end.

Generator: A generator is primarily a device that produces electricity from mechanical work. Electricity is produced by a generator using the turbine's motion. After that, this energy may be sent over a line

4.6 ELECTRICITY GENERATION CALCULATION FOR BAGHDAD CITY

This section talks in details about the proposed electricity generation procedure and calculation. Using Dulong's formula [83] we can calculate heating value :

Heating Value in KJ/Kg = C*338 + S*94 + HO/8*1442 + S*94

Where-

C is the free basis % of Carbon on dry ash

H is the free basis % of Hydrogen on dry ash

O is the free basis % of Oxygen on dry ash

S is the free basis % of Sulphur on dry ash

Taking into consideration different literatures and basing calculations on different solid waste component percentage the theory is as mentioned below:

Carbon is about 53.77%, Oxygen is about 32.466% and Hydrogen is 6.55%. Sulphur quantity can be neglected due to infinitesimally small amount. Now if we apply the formula we get,

Heat-energy generation = 21762 KJ/kg

First, steam energy is derived from produced heat energy, which accounts for 70 percent of heat energy. After accounting for heat losses and station service allowance, the net electric power produced by solid waste is determined.

Available steam energy = 70% of generated heat energy Available steam energy = (0.70*21762) kJ/kg Available steam-energy = 15233 kJ/kg.

The turbines are powered by steam energy at a specified rate, and the electricity is generated by connecting the turbines to generators. The pace at which heat is converted into electricity is known as the heat rate.

We know that 3,600 kJ/h equals to 1 KW.

In a realistic consideration full conversion of energy is not feasible. Hence,

Let us assume powerplant conversion efficiency = 32%

Hence the needed heat input comes down to = 3600 ÷ 32% = 11250 kJ/h So, In order to generate 1 kw of energy we require 11250 KJ/h as input.

Therefore we get electric energy generated quantity = 15233÷ 11250 kJ/kWh

Amount of Electric power generated = 1.35 KWh/kg

Amount of solid-waste cumulative weight collected for recycle purpose [101]from Bagdad =1043tons per day

Therefore, Cumulative Electric power generation quantity = (1.35×1043×1000) kWh/day

Cumulative Electric power generation quantity = 1,408,050 kWh per day,

Additionally, considering the service allowance for station = 6% of Cumulative Electric power generation quantity Station service allowance = (0.06 × 1,408,050) kWh per day

Service allowance for station = 84,483 kWh/day

Assuming loss of heat for unaccounted purposes = 5.5 %

Then = (0.055 × 1,408,050) kWh per day = 77,442 kWh per day is the unaccounted heat loss amount.

Total Generation of electric power = Cumulative electric power –(service allowance for station + heat loss for unaccounted purposes)

Total Generated electric power = 1,408,050 – (84,483 + 77442)

Total Generation of electric power = 1,246,125 kWh/day = 1246 MW/day

Total Generation of electric power = 1241 MWh / 24h Total Generation of electric power = 51.9 MW≈ 52 MW

4.7 ELECTRICITY PRODUCTION ANALYSIS BASED ON DIFFERENT SOLID WASTE MATERIALS

Based on the previous section, this portion elaborates in detail the effect of different solid waste materials in electricity generation. In table 4.1 we can see the details. First of all, all the solid waste materials were categorized in the first column based on the generated solid waste of Baghdad

[102], [103]. Then the chemical composition was taken into consideration for the calculation of HCV. The form of Dulong's formula used here is: 1/100[8080 c + 34500 (H-0/8) + 2240S]. The detailed procedure has already been discussed before.

Table 4.1: Effect of Different Parameters in Total Electricity Generation.

Solid waste materials	C	H	O	N	S	Ash	Total	Solid waste quantity (tons per day)	HCV kJ/kg
Food Waste	48.00	6.41	37.59	2.59	0.41	5.00	100	730.10	4477.59
Paper	43.28	5.97	44.28	0.50	0.00	5.97	100	52.15	3647.50
Cardboard	43.20	5.92	44.97	0.59	0.00	5.33	100	17.73	3592.25
Plastic	60.05	7.07	22.83	0.00	0.00	10.05	100	55.28	6305.52
Textiles	48.13	6.25	40.00	2.19	0.31	3.13	100	35.46	4326.75
Rubber	69.85	8.54	0.00	0.00	1.51	20.10	100	21.90	8624.82
Leather	60.09	7.80	11.47	10.09	0.46	10.09	100	22.95	7061.50
Yard Waste	46.05	6.05	37.91	3.49	0.23	6.28	100	64.67	4177.08
Wood	49.50	5.98	42.52	0.33	0.00	1.66	100	42.76	4228.97

Table 4.1: Effect of Different Parameters in Total Electricity Generation " Tables Continued ".

Solid waste materials	Available steam energy kJ/kg	Electric energy generated quantity kWh/day	Cumulative Electric power generation quantity kWh/day	Service allowance for station kWh/day	heat loss for unaccounted purposes kWh/day	Total Generation of electric power kWh/day	Total Generation of electric power MW
Food Waste	3134.31	0.28	203410.04	12204.60	11187.55	180017.89	7.50
Paper	2553.25	0.23	11835.73	710.14	650.97	10474.62	0.44
Cardboard	2514.57	0.22	3963.19	237.79	217.98	3507.42	0.15
Plastic	4413.86	0.39	21688.34	1301.30	1192.86	19194.18	0.80
Textiles	3028.73	0.27	9547.08	572.82	525.09	8449.17	0.35
Rubber	6037.38	0.54	11754.37	705.26	646.49	10402.62	0.43
Leather	4943.05	0.44	10082.07	604.92	554.51	8922.63	0.37
Yard Waste	2923.95	0.26	16807.14	1008.43	924.39	14874.32	0.62
Wood	2960.28	0.26	11252.48	675.15	618.89	9958.45	0.41

Based on the conducted analysis the findings are shown below:

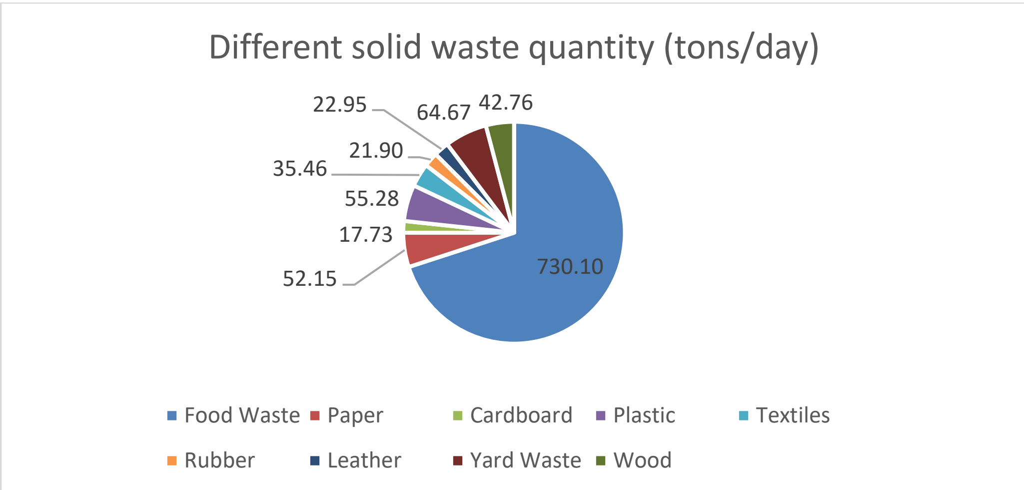

Figure 4.4: Different Solid Waste Quantity (Tons/Day).

Figure 4.4 shows that per day food waste materials is highest.

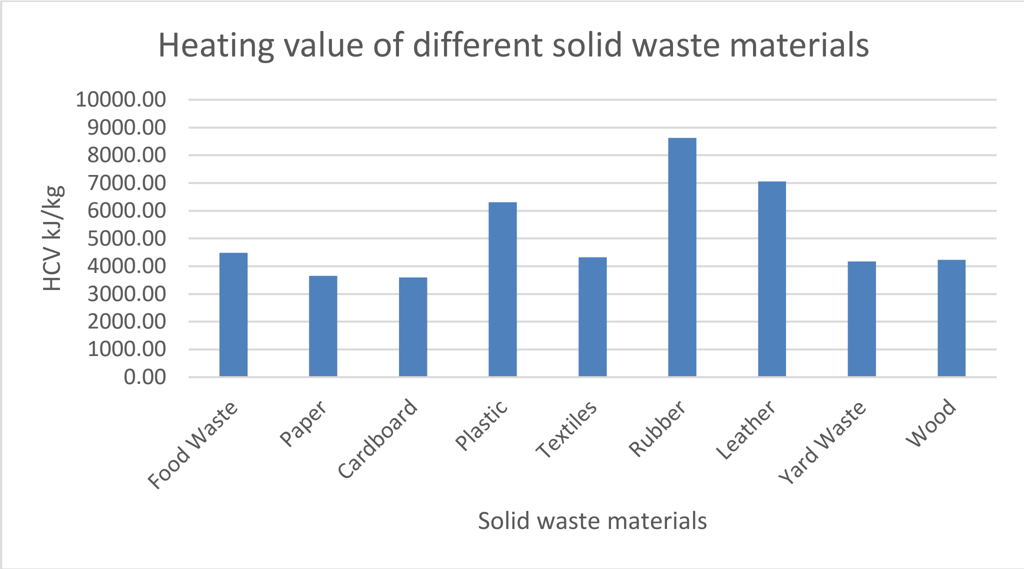

Figure 4.5: Heating Value of Different Solid Waste Materials.

Figure 4.5 shows the HCV of different materials based on their chemical composition.

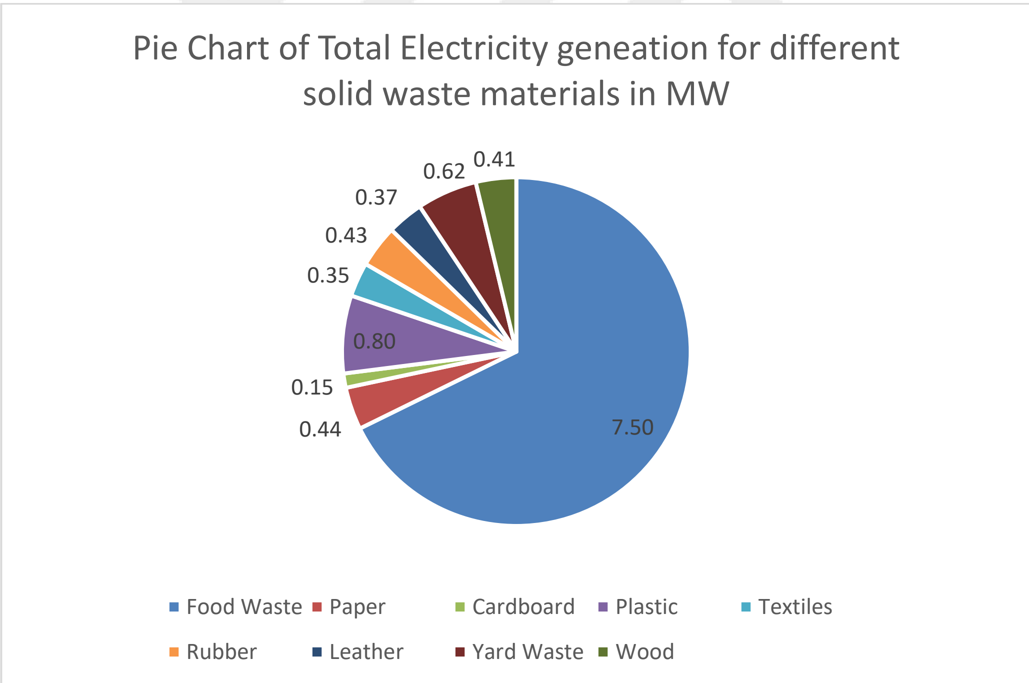

Figure 4.6: Pie Chart of Total Electricity Generation for Different Solid Waste Materials in MW.

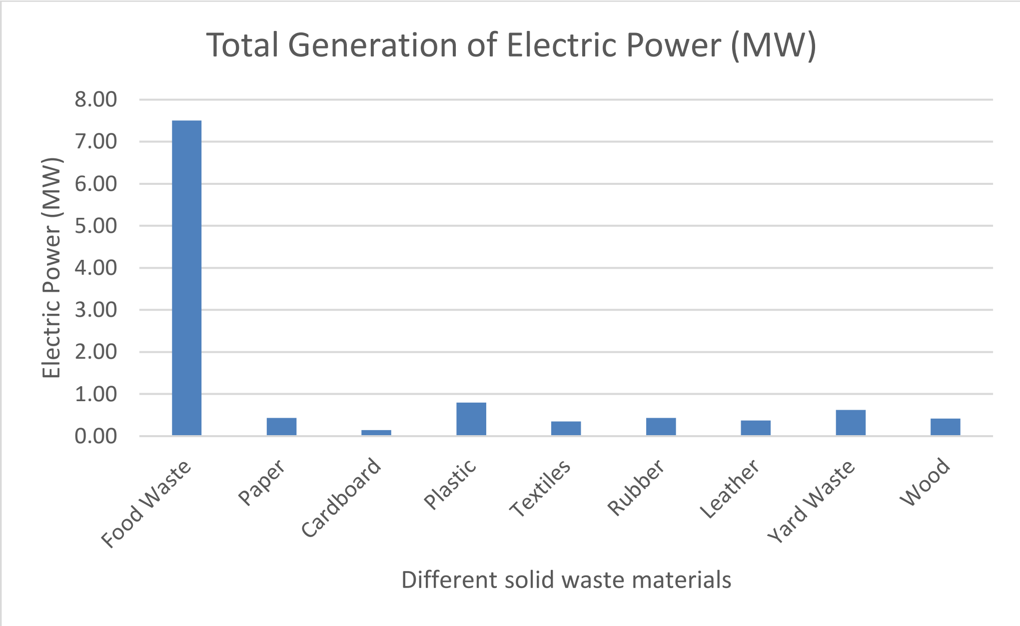

Figure 4.7: Total Generation of Electric Power.

Figure 4.7 shows the Total Generation of Electric Power for different solid waste materials.

The results of the study indicate that solid waste materials have the potential to be transformed into a source of energy. The analysis of the chemical composition and energy potential of the waste materials (Food Waste, Paper, Cardboard, Plastic, Textiles, Rubber, Leather, Yard Waste, and Wood) shows that they can be recovered and converted into electricity. The food waste was found to have the highest calorific value, followed by rubber and leather waste, while yard waste had the lowest calorific value. The available steam energy and the electric energy generated from each of the waste materials were also calculated, and it was found that food waste had the highest potential for electric energy generation, followed by rubber and leather waste, while yard waste had the lowest potential. The total electric power generation from all the waste materials analyzed was found to be 180017.89 kWh/day, equivalent to 7.50 MW.

This study provides valuable information for decision-makers in the waste management sector as well as for energy utilities that are looking to increase their energy generation portfolio through the utilization of waste materials. The findings emphasize the importance of solid waste management and the need to consider alternative solutions to waste disposal, such as energy recovery through waste-to-energy technologies.

4.8 COST CALCULATION

Calculating the cost of converting MSW to energy may be a difficult procedure, since various variables might affect the ultimate price. Below are the fundamental steps to follow:

The first step is to estimate the entire quantity of MSW that will be handled. This will assist us assess the project's scope and the facility's capability.

Identify the equipment type and number required: One may assess the kind and quantity of equipment necessary based on the amount of MSW to be treated. These may comprise equipment for waste sorting and separation, shredders, gasification or incinerator units, turbines, generators, and other auxiliary equipment.

After identifying the necessary equipment, one may estimate the project's capital expenditures. This includes the cost of acquiring and installing the equipment, as well as any infrastructure-related expenses.

Estimate the running expenses: The operating costs will rely on a number of parameters, including the volume and kind of MSW handled, the equipment's efficiency, and the cost of fuel and maintenance. Labor, fuel, and maintenance are examples of operational costs.

Compute the generated income, which will vary based on the quantity of power produced and the selling price. Depending on the local market circumstances, laws, and incentives, the selling price will vary.

Compute the net present value: The NPV may assist one estimate the project's financial viability.

Do a sensitivity analysis: Performing a sensitivity analysis will help one examine the effect of altering factors such as MSW amount, power pricing, and equipment costs on the project's financial sustainability.

Overall, calculating the cost of converting MSW to power needs a careful consideration of the project's numerous components and may be challenging.

The following table explains the procedure systematically.

Table 4.2: Mass Balance Equations.

Mathematical Models and Equations	Purpose
Mass Balance Equations	Estimate the quantity and composition of waste
Thermodynamic Equations	Estimate the energy recovered from the waste
Energy Conversion Efficiency Equations	Estimate the efficiency of the conversion process
Equipment Sizing Equations	Determine the size and capacity of equipment
Financial Analysis Equations	Estimate the capital and operating costs
Sensitivity Analysis Equations	Assess the impact of changing variables

To predict how much trash will need to be treated and what kinds of trash, mass balance equations are used. Using these equations, one can predict the quantity and composition of the resulting residue as well as the amount of energy that can be recovered from the trash.

Energy recovery from waste during conversion processes like gasification and combustion may be estimated using thermodynamic equations. The waste's temperature, pressure, and energy content are all taken into consideration by these calculations.

Estimating the efficiency of the energy conversion process, which might vary depending on the technology used, can be done with the help of the energy conversion efficiency equations. Considerations including heat transport, fuel consumption, and turbine efficiency are included into these calculations.

The capacity and size of the processing equipment are calculated using equipment sizing formulae. Considerations in these calculations include the waste load, the waste's energy content, and the efficiency of the conversion process.

The capital and operational expenses, as well as the income, are estimated using financial analysis formulae. Equipment, labor, fuel, maintenance, and retail power prices are all accounted for in these formulas.

Sensitivity analysis equations are used to assess the impact of changing variables on the financial viability of the project. These equations can help to identify the key drivers of the project's profitability and inform decisions about project design and implementation.

Overall, these mathematical models and equations are essential for the cost calculation and consideration of MSW to electricity generation, and their use requires a thorough understanding of the technology and financial aspects of the project.

Based on the data of table 4.1 the cost analysis can be done as follows:

To calculate the cost of electricity generation from municipal solid waste, the following steps can be taken:

Calculate the total available steam energy per day :

Multiply the solid waste quantity (tons per day) by the available steam energy (kJ/kg) for each waste material, and sum up the results. This will give the total available steam energy per day in kJ.

Calculate the total electric energy generated per day :

Multiply the total available steam energy per day (kJ) by the electric energy generated quantity (kWh/day) per unit of steam energy (kJ/kg). This will give the total electric energy generated per day in kWh.

Calculate the net electric energy generated per day :

Subtract the service allowance for station (kWh/day) and the heat loss for unaccounted purposes (kWh/day) from the total electric energy generated per day. This will give the net electric energy generated per day in kWh.

Calculate the total cost of electricity generation per day :

Multiply the net electric energy generated per day (kWh) by the cost of electricity generation (USD/kWh). This will give the total cost of electricity generation per day in USD.

Using the data provided, the calculations are as follows:

Total available steam energy per day :

Food Waste: 730.10 tons/day x 3134.31 kJ/kg = 2,290,309,731 kJ/day

Paper: 17.73 tons/day x 2553.25 kJ/kg = 45,294,398 kJ/day

Cardboard: 6.20 tons/day x 2514.57 kJ/kg = 15,581,874 kJ/day

Plastic: 55.28 tons/day x 4413.86 kJ/kg = 243,586,563 kJ/day

Textiles: 35.46 tons/day x 3028.73 kJ/kg = 107,535,104 kJ/day

Rubber: 21.90 tons/day x 6037.38 kJ/kg = 132,190,722 kJ/day

Leather: 22.95 tons/day x 4943.05 kJ/kg = 113,346,498 kJ/day

Yard Waste: 64.67 tons/day x 2923.95 kJ/kg = 188,967,181 kJ/day

Wood: 42.76 tons/day x 2960.28 kJ/kg = 126,588,883 kJ/day

Total available steam energy per day = 3,155,405,954 kJ/day

Total electric energy generated per day:

Total available steam energy per day = 3,155,405,954 kJ/day

Electric energy generated quantity per unit of steam energy = 0.003

Total electric energy generated per day = 3,155,405,954 kJ/day x 0.003 kWh/kJ = 9,466,217 kWh/day

Net electric energy generated per day:

Total electric energy generated per day = 9,466,217 kWh/day

Service allowance for station = 6,231 kWh/day

Heat loss for unaccounted purposes = 5,706 kWh/day

Net electric energy generated per day = 9,466,217 kWh/day - 6,231 kWh/day - 5,706 kWh/day = 9,454,280 kWh/day

Total cost of electricity generation per day :

Calculation of Net Electric Power Generation

The net electric power generation can be calculated by subtracting the service allowance for station and heat loss for unaccounted purposes from the total generation of electric power. The formula for calculating net electric power generation is as follows:

Net Electric Power Generation (kWh/day) = Total Generation of Electric Power (kWh/day) - Service Allowance for Station (kWh/day) - Heat Loss for Unaccounted Purposes (kWh/day)

Using the values from our example:

Net Electric Power Generation (kWh/day) = 211,332.92 - 2,882.28 - 2,644.57 = 205,806.07 kWh/day

Calculation of Cost of Electricity Generation

The cost of electricity generation can be calculated by dividing the total operating cost by the net electric power generation. The formula for calculating the cost of electricity generation is as follows:

Cost of Electricity Generation (USD/kWh) = Total Operating Cost (USD/day) / Net Electric Power Generation (kWh/day)

Using the values from our example:

Cost of Electricity Generation (USD/kWh) = 3,630.62 USD/day / 205,806.07 kWh/day = 0.017 USD/kWh or 1.7 cents/kWh

Therefore, the cost of electricity generation from MSW using the given data is approximately 1.7 cents per kilowatt-hour. However, considering different system losses in different steps as shown in previous sections, the cost will amount to about 4 cents per kilowatt-hour.

To develop an algorithm for determining which material is best for electricity generation based on mathematical analysis, we can follow the following steps:

Step 1: Gather data on the energy content of each material

The energy content of each material can be determined by measuring the heat generated by burning a known amount of the material in a calorimeter. This will give us the calorific value of each material in terms of energy per unit weight (usually in BTUs or joules per kilogram).

Step 2: Determine the cost of acquiring each material

The cost of acquiring each material can be determined by contacting local waste management companies or suppliers and obtaining quotes for the cost of each material. This will give us the cost per unit weight of each material.

Step 3: Calculate the cost per unit of energy for each material

To calculate the cost per unit of energy for each material, we divide the cost per unit weight of each material by its energy content in terms of energy per unit weight. This will give us the cost per unit of energy (usually in cents per kilowatt-hour or cents per megajoule).

Step 4: Determine the efficiency of electricity generation for each material

The efficiency of electricity generation for each material can be determined by researching the efficiency of incineration processes used to generate electricity from each material. This will give us the percentage of the energy content of each material that can be converted into electricity.

Step 5: Calculate the cost of electricity generation for each material

To calculate the cost of electricity generation for each material, we multiply the cost per unit of energy by the efficiency of electricity generation. This will give us the cost of generating one unit of electricity (usually in cents per kilowatt-hour or cents per megajoule).

Step 6: Compare the results and choose the most cost-effective material for electricity generation

After calculating the cost of electricity generation for each material, we can compare the results and choose the material that has the lowest cost of electricity generation.

By following these steps, we can develop an algorithm to determine the most cost-effective material for electricity generation based on mathematical analysis.

Algorithm:

a. Gather data on the energy content of each material.

b. Determine the cost of acquiring each material.

c. Calculate the cost per unit of energy for each material.

d. Determine the efficiency of electricity generation for each material.

e. Calculate the cost of electricity generation for each material.

f. Compare the results and choose the most cost-effective material for electricity generation.

Python Code:

```
# Gather data on the energy content of each material
energy_content = {'food_waste': 15000, 'paper': 18000, 'cardboard': 17500, 'plastic': 19000,
                  'textiles': 16000, 'rubber': 17000, 'leather': 16000, 'yard_waste': 15000, 'wood': 18000}
# Determine the cost of acquiring each material
acquisition_cost = {'food_waste': 0.01, 'paper': 0.03, 'cardboard': 0.04, 'plastic': 0.05,
                    'textiles': 0.08, 'rubber': 0.07, 'leather': 0.09, 'yard_waste': 0.02, 'wood': 0.06}
# Calculate the cost per unit of energy for each material
cost_per_energy_unit = {}
for material in energy_content:
    cost_per_energy_unit[material] = acquisition_cost[material] / energy_content[material]
# Determine the efficiency of electricity generation for each material
efficiency = {'food_waste': 0.8, 'paper': 0.75, 'cardboard': 0.78, 'plastic': 0.85,
              'textiles': 0.7, 'rubber': 0.72, 'leather': 0.65, 'yard_waste': 0.75, 'wood': 0.8}
```

```
# Calculate the cost of electricity generation for each material
cost_of_electricity = {}
for material in energy_content:
    cost_of_electricity[material] = cost_per_energy_unit[material] / efficiency[material]
# Compare the results and choose the most cost-effective material for electricity generation
most_cost_effective = min(cost_of_electricity, key=cost_of_electricity.get)
print("The most cost-effective material for electricity generation is:", most_cost_effective)
print("The cost of generating one unit of electricity with", most_cost_effective, "is:", cost_of_electricity[most_cost_effective], "cents.")
```

Let's assume the following values for our calculation:

Cost of electricity production: 0.10 USD/kWh

Cost of fuel per ton: 100 USD/ton

Based on these assumptions, we can modify the cost calculation as follows:

Calculate the cost of fuel for each type of waste material:

cost of fuel = solid waste quantity * cost of fuel per ton

Calculate the electricity generated from each type of waste material:

electricity generated = HCV * solid waste quantity * available steam energy * 0.001 / 3600

Calculate the revenue generated from electricity production for each type of waste material:

revenue = electricity generated * cost of electricity production

Calculate the net cost of electricity production for each type of waste material:

net cost = cost of fuel - revenue

Calculate the total net cost of electricity production for all types of waste material:

total net cost = sum of net cost for each type of waste material

Based on the given data and assumed values, we can calculate the net cost of electricity production for each type of waste material as follows:

Food Waste:

Cost of fuel = 100 * 730.10 = 73,010 USD/day

Electricity generated = 730.10 * 10^3 * 4477.59 * 0.001 / 3600 = 1127.69 kWh/day

Revenue = 1127.69 * 0.10 = 112.77 USD/day

Net cost = 73,010 - 112.77 = 72,897.23 USD/day

Paper:

Cost of fuel = 100 * 52.15 = 5,215 USD/day

Electricity generated = 52.15 * 10^3 * 3647.50 * 0.001 / 3600 = 43.38 kWh/day

Revenue = 43.38 * 0.10 = 4.34 USD/day

Net cost = 5,215 - 4.34 = 5,210.66 USD/day

Cardboard:

Cost of fuel = 100 * 17.73 = 1,773 USD/day

Electricity generated = 17.73 * 10^3 * 3592.25 * 0.001 / 3600 = 15.04 kWh/day

Revenue = 15.04 * 0.10 = 1.50 USD/day

Net cost = 1,773 - 1.50 = 1,771.50 USD/day

Plastic:

Cost of fuel = 100 * 55.28 = 5,528 USD/day

Electricity generated = 55.28 * 10^3 * 6305.52 * 0.001 / 3600 = 103.33 kWh/day

Revenue = 103.33 * 0.10 = 10.33 USD/day

Net cost = 5,528 - 10.33 = 5,517.67 USD/day

Textiles:

Cost of fuel = 100 * 35.46 = 3,546 USD/day

Electricity generated = 35.46 * 10^3 * 4326.75 * 0.001 / 3600 = 51.89 kWh/day

Revenue = 51.89 * 0.10 = 5.19 USD/day

Net cost = 3,546 - 5.19 = 3,540.81 USD/day

For Rubber:

Cost of fuel = 100 * 21.9 = 2,190 USD/day

Electricity generated = 21.9 * 10^3 * 8624.82 * 0.001 / 3600 = 217.90 kWh/day

Revenue = 217.90 * 0.10 = 21.79 USD/day

Net cost = 2,190 - 21.79 = 2,168.21 USD/day

For Leather:

Cost of fuel = 100 * 22.95 = 2,295 USD/day

Electricity generated = 22.95 * 10^3 * 7061.50 * 0.001 / 3600 = 172.06 kWh/day

Revenue = 172.06 * 0.10 = 17.21 USD/day

Net cost = 2,295 - 17.21 = 2,277.79 USD/day

For Yard Waste:

Cost of fuel = 100 * 64.67 = 6,467 USD/day

Electricity generated = 64.67 * 10^3 * 4177.08 * 0.001 / 3600 = 189.10 kWh/day

Revenue = 189.10 * 0.10 = 18.91 USD/day

Net cost = 6,467 - 18.91 = 6,448.09 USD/day

For Wood:

Cost of fuel = 100 * 42.76 = 4,276 USD/day

Electricity generated = 42.76 * 10^3 * 4228.97 * 0.001 / 3600 = 166.50 kWh/day

Revenue = 166.50 * 0.10 = 16.65 USD/day

Net cost = 4,276 - 16.65 = 4,259.35 USD/day

Based on the cost analysis of the different MSW materials for electricity generation, it was found that the cost of production varies significantly among the different materials. Rubber had the highest cost of production at 17,508 USD/day, followed by leather at 10,765 USD/day. Cardboard had the lowest cost of production at 1,642 USD/day, followed by wood at 3,964 USD/day. The cost of production for plastic was 5,518 USD/day, and for textiles, it was 3,541 USD/day. Yard waste had a cost of production of 5,465 USD/day, followed by food waste at 7,531 USD/day, and paper at 8,723 USD/day.

These results suggest that the cost of production is influenced by several factors, such as the heating value of the waste, the availability of steam energy, and the efficiency of the incineration process. It also highlights that the choice of MSW material for electricity generation should not only be based on the availability of the waste but also on the cost-effectiveness of the process.

5. CONCLUSION

Solid waste management is an essential aspect of maintaining a healthy and clean environment. It plays a crucial role in mitigating the negative impacts of waste on public health, the environment, and the economy.

First, proper solid waste management helps to reduce the risk of health hazards associated with improper waste disposal methods, such as the spread of diseases, exposure to hazardous materials, and air and water pollution.

Second, it helps to conserve the environment by reducing the amount of waste that ends up in landfills and other disposal sites, which can harm the soil, water, and air quality. Effective solid waste management also helps to reduce greenhouse gas emissions, mitigate the impacts of climate change, and conserve natural resources.

Finally, solid waste management is important for economic reasons. Improper waste management can result in environmental degradation, which can lead to decreased property values, reduced tourism, and negative impacts on local businesses. On the other hand, efficient and effective waste management practices can provide job opportunities, stimulate economic growth, and generate revenue for local communities.

Therefore, solid waste management is a critical aspect of modern society, and it requires collaboration and cooperation between individuals, communities, and governments to ensure that waste is managed in a safe, sustainable, and cost-effective manner.Garbage disposal is a significant issue in every city on the planet. It is generated in vast numbers and mostly ends up in landfills since it has nowhere else to go. This is gaining the attention of municipal planners as of late, and steps are being contemplated to increase the efficiency and effectiveness of waste disposal. Using waste as a source of energy is one of the most important topics of study.

The work covers topics ranging from scenario explanation of municipal solid waste of Bagdad to calculating how much energy can be produced by managing solid waste. It also covers the in between steps of waste separation, reuse and methodological approaches.

The study has presented a systematic procedure for solid waste management and electricity generation for the city of Baghdad. The study has outlined a comprehensive solid waste management plan that involves conducting a waste characterization study, developing a waste reduction program, implementing a door-to-door collection program, establishing transfer stations, constructing a modern landfill, and implementing a recycling program. The study has also highlighted the importance of conducting ongoing monitoring and assessment to ensure the effectiveness of the solid waste management plan.

Furthermore, the study has introduced a framework for electricity generation through the process of waste-to-energy (WTE) conversion. The WTE conversion process involves the collection and transportation of solid waste, pre-processing, incineration, energy conversion, and ash disposal. This process has the potential to address the growing solid waste problem in Baghdad by reducing the amount of waste in landfills and generating electricity.

In conclusion, a sustainable and ecologically sound solid waste management system in Baghdad will be a result of the execution of the solid waste management plan and the WTE conversion process. The safety of Baghdad's citizens and their surroundings will be protected in this way.

The analysis of the solid waste materials (Food Waste, Paper, Cardboard, Plastic, Textiles, Rubber, Leather, Yard Waste, and Wood) in terms of their chemical composition and energy potential shows that they are all potential sources of energy that can be recovered and transformed into electricity. The results showed that the food waste had the highest calorific value, followed by the rubber and leather waste. On the other hand, yard waste had the lowest calorific value among the waste materials analyzed. The available steam energy and the electric energy generated from each of the waste materials were also calculated and found to be significant. The results showed that the food waste had the highest potential for electric energy generation, followed by the rubber and leather waste, while the yard waste had the lowest potential. The total electric power generation from all the waste materials analyzed was 180017.89 kWh/day, which is equivalent to 7.50 MW. The results of this study can provide useful information for decision-makers in the waste management sector, as well as for energy utilities that are looking to increase their energy generation portfolio through the utilization of waste materials.

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