2025

Modelling of municipal solid waste use for steam generation for industrial and hospitality sector.

Omare, Jeremy Warioba
School of Computing and Engineering Sciences
Strathmore University

Recommended Citation

Omare, J. W. (2025). *Modelling of municipal solid waste use for steam generation for industrial and hospitality sector* [Strathmore University]. http://hdl.handle.net/11071/15972

Modelling of Municipal Solid Waste Use for Steam Generation for Industrial and Hospitality Sector

Omare Jeremy Warioba

ADM: 150960

Dissertation Submitted to the School of Computing and Engineering Sciences in Partial Fulfillment of the Requirements of the degree of Master of Science in Sustainable Energy Transitions of Strathmore University

MARCH, 2025

DECLARATION

I confirm that this study has not been submitted beforehand and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the proposal itself.

Signature………… ………… Date………26th March, 2025……….

Jeremy Warioba Omare

Admission No 150960

Approval

I have given my permission in my capacity as the academic advisor for Jeremy Warioba Omare's submission of this dissertation to the School of Computing and Engineering Sciences.

Signature……………………. Date….26th March 2025.….

Dr. Victor Rop

Lecturer

Strathmore University

DEDICATION

To my parents, who were so sure that I'd grow up to be a man of character, that I did. For the years of steadfast support that helped me go this far, I thank my instructors and teachers. To my colleagues who have consistently joined me during brainstorming meetings and classwork sessions.

ACKNOWLEDGEMENT

The successful completion of this dissertation has been made possible through the invaluable support and guidance I have received from various individuals and institutions. I extend my deepest gratitude to my supervisor, Dr. Victor Rop, and my thesis lecturer, Dr. Eng. Fenwicks Musonye, whose intellectual guidance and mentorship have been instrumental throughout this research journey. Their unwavering support and insightful feedback have significantly contributed to the quality of this work.

I am also sincerely grateful to my classmates and colleagues in the energy efficiency sector, whose encouragement and reminders, though at times daunting served as a constant motivation to complete this work in a timely manner. Their support has been invaluable in keeping me focused and committed to my research.

I gratefully acknowledge the generous support of the Liechtenstein REED/TEA-LP Scholarship, which not only offered me the opportunity to pursue my master's degree but also provided essential financial assistance that helped bring this dream to fruition. Their commitment to nurturing future leaders has inspired a forward-thinking approach in both my research and career.

Furthermore, I express my heartfelt appreciation to my family; my father, Daniel Omare, my mother, Kerubo Ragira, and my siblings, Benson Omare, Mercy Loy, and Abby Bhoke. Their unwavering emotional and moral support has been a source of strength and encouragement throughout this academic endeavor.

I am especially indebted to my parents for their financial support, which made this work possible. However, any errors or shortcomings in this dissertation remain solely my responsibility.

ABSTRACT

The cumulative demand for steam in the hospitality and industrial sectors has led to rising financial and environmental costs due to the prevalent use of biomass for steam generation. This challenge has intensified by issues such as resource depletion, competition for land with food crops, and the bulky nature of biomass, which complicates energy management. Previous attempts to use Municipal Solid Waste (MSW) as an alternative fuel for steam generation have yielded inconclusive results, underscoring the need for further research to establish its feasibility as a replacement for biomass. This study modeled the use of MSW for steam generation in industrial and hospitality sectors. The main objective of this study was to model transport and treatment processes in MSW steam generation. Secondary data was collected from three zones in Nairobi, an industry setup and a hotel, each characterized by different energy & waste profiles stemming from varied commercial and social activities. The data collected was analyzed using a developed model incorporating governing equations for calorific value calculations, transport, treatment, and the Levelized Cost of Steam (LCOS). Under three scenarios, the calorific values of MSW and biomass (Eucalyptus globulus) were analyzed, revealing that MSW possessed a superior energy density at 23.80 MJ/kg compared to biomass at 17.34–17.43 MJ/kg. Proximate analysis of Nairobi's MSW highlighted organic waste dominates at 65.4% of the total waste and moisture content was reduced from 19.03% to 15% via drying to enhance combustion efficiency. Also, transportation costs were modeled for two collection points, emphasizing distance-driven variations. The techno-economic framework computed the LCOS by integrating capital and operational expenditures, as well as transport and treatment costs. Results demonstrated the cost-effectiveness of MSW, with LCOS values of 1.48–1.49 Ksh/kg and 2.24–2.32 Ksh/kg for the two companies analyzed respectively. This shows 25–26% reduction over biomass. Scenario analyses confirmed MSW's resilience to cost escalations, as it maintained lower costs than biomass. Although costs varied non-linearly with transportation and drying, the processes added more operational annually, but the overall LCOS remained economically viable, compared to biomass. MSW reduced feedstock demand by 27% and storage requirements, thereby aligning with Kenya's waste management and renewable energy goals. The proposed model offered a replicable framework for optimizing MSW utilization in steam generation, emphasizing localized waste characterization and policy cost incentives. Recommendations include advancing waste-to-energy conversion studies, spatial transport optimization, and the integration of social economic factors in future models. These findings supported the adoption of MSW to mitigate production costs, reduce deforestation, and foster sustainable urban energy transitions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DEFINITION OF KEY TERMS

Municipal Solid Waste	Municipal Solid Waste (MSW) refers to the solid waste generated by households, institutions, and commercial establishments within a municipality or urban area.
Waste to Energy Technology	Waste-to-Energy (WTE) technology is a process that involves the conversion of non-recyclable solid waste materials into usable energy, typically in the form of electricity, heat, or fuel
Steam	Steam is the gaseous phase of water, formed when water boils or evaporates.
Boiler	A boiler is a closed vessel in which water is heated, either by the combustion of fuel or through electric heating. The heated or vaporized fluid exits the boiler for use in various processes or heating applications.

ABBREVIATIONS & ACRONYMS

MSW	Municipal Solid Waste
WTE	Waste to Energy Technology
KJ	Kilo-Joules
MJ	Mega-Joules
Ksh	Kenya Shilling
CAPEX	Capital Expenditure
OPEX	Operation Expenditure
NCC	Nairobi City County
KNBS	Kenya National Bureau of Statistics
NEMA	National Environment
LCOS	Levelized cost of steam
SDG	Sustainable Development Goal
VBA	Visual Basic Application
kWh	Kilowatt Hour
NACOSTI	National Commission for Science, Technology and Innovation
LCOE	Levelized cost of energy
NCV	Net Calorific Value
GCV	Gross Calorific Value
SU-IERC	Strathmore University Institutional Scientific and Ethics Review Committee

CHAPTER 1:INTRODUCTION

1.1 Background of the Study

Steam production costs have been rising in industrial and hospitality institutions in the world more so hotels, processing and production plants are the most affected. Mohsen (2023) attributes the rise of steam production costs to the rising costs of energy in fossils fuels and woody biomass that are commonly used as the source of fuel. There are also associated costs such as constant maintenance of the boilers, which influence the final levelized cost of steam, at which facilities get to buy the steam. A study by Munich Re Company (2024), attributed maintenance as one of the enormous expenses that add up to the rising costs of steam. There are costs associated with technology usage, such as parts replacement, service calls, inspections, emissions costs, and calibrations to think about.

Steam is generated primarily through combustion of fossil fuels. Perera (2018) acknowledges that such combustion of fossil fuels and biomass primes the upsurge in the concentration levels of carbon dioxide and other greenhouse gases in the ecosystem, where carbon dioxide is a major influence behind global warming. The steam production costs impel the financial performance of the industrial and hospitality setups that function with direct usage of steam. Dahash et al. (2022), cites the rising costs of steam and associated emission costs as the contributing influences on the increase in price of production.

The industrial processes are categorized by either use of steam directly or indirectly. These industrial processes comprise direct heating, production process of separation and distillation. In hospitality areas, steam is used in heating, air-drying in laundry areas, sauna and therapy. In both hospitality and industrial setups, steam is used in the driving of prime movers such calendar machines, dryers amid other processing machines.

To adapt to the costs faced by the hospitality and industrial setups, there have been attempts to reduce the financial and emission costs of steam production in both industrial and hospitality setups. Several methods of reducing these costs, through fuel switching and technology change, have been advanced. These methods include the use of electricity to generate steam, use of municipal solid waste as a fuel, technologies such as steam generators and tools for efficient production such as exergy analysis & learning curves (Khaleel, Basim, Bin, & Khalil, 2022). There have been consistent efforts to carry out these options with the goal of getting a reduction to the cost of steam production and ensuring sustainable production to meet demands in hospitality and industrial applications.

Research by, (Trust) 2014 indicates that fuel substitution and associated tools may assist in reduction of steam production costs in industrial and hospitality set ups. However, these initial findings are provisional, and further empirical investigation is required. The use of municipal solid waste as a fuel, for example, has typically been used as tool for solid waste management, thus it is a viable source of fuel. There have been attempts to assess the use of municipal solid waste as a fuel, based on the technologies available and the application of use. Municipal solid waste usage as a fuel specifically for industrial and hospitality can be characterized based on the location, technology used and the application.

In Kenya’s industrial and hospitality setups, steam is produced primarily through boilers. Steam boilers function as the prop of production and engineering operations across manufacturing sectors in Kenya, including agriculture, textiles and food processing (Mark, 2024). Despite this, majority of the existing boiler systems for steam production still employ now-outdated legacy technologies. These older technologies lack the current novelties needed to address increasing challenges around inefficiency, excessive downtimes, and safety risks.

The technology in use for steam generation dictates the suitable fuel for usage. The Ministry of Energy Kenya (2020), indicates that industrial processing and manufacturing plants use Industrial Diesel Oil (IDO) with a mix of biomass to meet their energy needs. Most of these setups own the infrastructure and the system to operate and maintain the boilers and steam systems. In the hospitality sector, woody biomass is commonly used in the form of bulky wood or pellets. Due to the consistent rise in the cost of biomass and diesel, businesses have resorted to buying steam as a service. This is a service where facilities procure steam, on demand from a third-party provider, thereby eliminating the need to own and operate an in-house steam generation infrastructure

Beth Nyaga (2023), acknowledges that businesses have shifted to buying steam as a service to try mitigate the production costs of steam. Some of the hospitality setups have adopted this model to meet sustainability and policy benchmarks. For example, Lean Energy Solutions Limited offers such a model solution for hospitality clients and medium-level industrial facilities (Lean Energy, 2025). In such a model, biomass is still used, and in older facilities heavy fuel oil is used. Elkelawy et al., (2022) observes that the biomass used is often transported from areas that harvest timber. Industries that heavily need consistent steam have storage for the fuel used for steam production. These inherent inputs influence the total cost of steam production, thus calls for the assessment for an alternative fuel for use in steam production in industrial and hospitality setups. This research, therefore, seeks to assess municipal solid waste for steam generation in industrial and hospitality areas.

1.2 Problem Statement

The cost of steam production cumulative has been increasing in the world because of financial and environmental costs. Financial costs caused by the rising prices of energy of fossil fuels such as coal, gasoline, industrial diesel oil, and petroleum, and emission costs due to rise in emission of gases that are injurious to the ecology, has resulted to increase of goods and services. This has resulted in price increases for goods and services.

In industrial and hotel processes, the prevalent need for steam has prompted a growing reliance on biomass-fed boilers. These boilers, while addressing the demand for steam, also have problems associated with resource depletion, woody biomass, and competition for land with food crops. The bulky nature of the biomass creates a challenge in the overall energy management of these establishments.

Attempts have been made to use Municipal Solid Waste as a substitute fuel in steam generation. Inversely, the outcomes of this intervention have not been substantial. Technical challenges such as fuel heterogeneity; logistic challenges and economic viability remain uncertain. Therefore, there is a necessity to conduct more studies to establish the feasibility of Municipal Solid Waste (MSW) as a pathway to replace biomass.

1.3 Study Objectives

1.3.1 Main Objective

The main objective of this research is to model municipal solid waste for steam generation in the industrial and hospitality sectors.

1.3.2 Specific Objectives

The general objective was achieved via the following specific objectives:

i. To evaluate the calorific values of biomass and municipal solid waste
ii. To quantify the amount of biomass consumption and energy used
iii. To model transport and treatment in municipal solid waste use for steam generation
iv. To conduct a techno-economic analysis of MSW as feedstock for steam generation

1.4 Research Questions

i. What are the calorific values for biomass and municipal solid waste?
ii. What is the amount of biomass and the corresponding energy used?
iii. What is the impact of distance and drying costs in the levelized cost of steam?
iv. What is the cost of steam generation from using MSW as feedstock?

1.5 Justification of the Study

The increasing demand for steam to sustain manufacturing and hospitality growth has caused a rise in the financial and environmental costs, due to the use of biomass in generation. Intercontinental, nationwide and private sector actors need to find better and sustainable ways of mitigating this increase in costs, while sustaining the value and quantity of the products and services.

Africa Energy Outlook report (2019), notes that the commercial activities that rely on oil and wood fuel contribute to 8.4% and 0.4%, to the GDP directly. This highlights the direct use case of fossil fuels in our social development. According to a report by the ministry of Environment and Forestry (2020), the government of Kenya has a goal line of enhancing forest cover to a minimum of 10 % of the National area by 2030. Woody biomass, being the primary source of fuel, for steam generation, offers a compelling reason for efforts to mainstream fuel switching initiatives. Steam demand in Kenya, more so in manufacturing has been on the upsurge in the last five years (KNBS, 2023). It is essential to focus on alternative ways of prudent steam generation. This will help to reduce the cost and resource depletion challenge.

1.6 Scope of the Study

This study focuses on modeling the use of municipal solid waste as a fuel for steam generation. The assessment integrates an analysis of the transportation and treatment (drying) processes involved in waste management. Additionally, the calorific value of municipal solid waste is compared with that of woody biomass, which is the current primary fuel. A techno-economic analysis is also conducted to determine the levelized cost of steam, providing insights into the feasibility of this alternative fuel source. The study is in Nairobi.

1.7 Limitation of Study

The study sought to model municipal solid waste use in steam generation, assess transport and treatment and how it affects the energy output and costs. Data quantities for biomass were collected from one hotel and one industrial setup in Nairobi. The treatment associated costs for woody biomass was assumed to be negligible, while transportation was not considered, as the facilities were assumed to produce their own biomass. Some thermal variables such as efficiencies for both MSW and woody biomass ware considered to be the same, hence this was not accounted for in the analysis. This work nevertheless assumes that the non-uniformity of secondary data used for determining waste characterization, proximate analysis, and transportation distances were a limitation. Data for variables like moisture content and cost of storage and separation were not uniform across all secondary sources. The modelling used a localized approach as it considers some variables unique to the two setups analyzed.

CHAPTER 2: LITERATURE REVEIW

2.1 Introduction

This chapter discusses the concepts, theories, and empirical studies about steam generation as used in industrial and hospitality processes. The first section elaborates the concept of steam generation where water boilers, steam use and types of fuels are explained. In the second part of this chapter, principles of municipal solid waste as a fuel have been described. The third part presents the philosophy and concept of combustion characteristics of MSW. Critical review of empirical studies in steam generation and MSW as a fuel and the study gaps have been assesed.

2.2 Theoretical review

2.2.1 Steam Generation

Steam generation is the process of producing steam by heating water. Steam is used in various processes and industries, including food processing, metal working, power generation, and chemical production. Given the broad application of steam, there are diverse ways of generating steam, and various technologies have been developed to suit different demands.

At the core, a steam generator is needed. This is a device that facilitates the heating of water to produce steam. The type of generator depends on what steam is required for. The common working principle used in steam generation is by transferring heat from the fuel source to water, boiling it, and generating steam. Under this concept, the steam generator can be a water or fire tube boiler.

2.2.2 Water Tube Boilers

Water tube boilers are regarded as the most efficient compared to other types of boilers as, they can generate a higher steam volume under high temperatures and operating pressures. Water tube boilers are commonly used in power plants and industrial settings where higher capacities are needed (Świątkowski, Kalisz, & Wnorowska, 2022). The main fuel source used in the water-tube Boiler is mainly fossil fuels (Khaleel, Basim, Bin, & Khalil, 2022). According to Takase et al. (2021), recent fuel technology has ventured into renewable energy, such as biomass and geothermal energy. To illustrate how Water tube boilers work, this study draws on an example of coal-fired power station, shown in the figures; 2.1, 2.2 & 2.3 below.

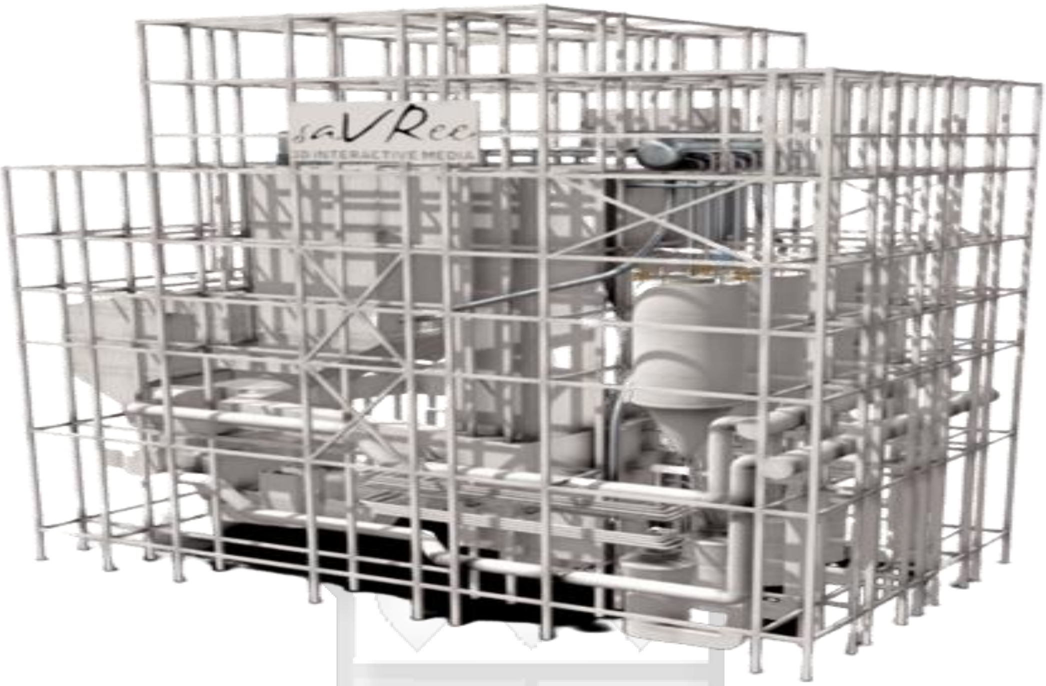


Figure 2.1: Water Tube Boiler

Source: (Savree, 2024)

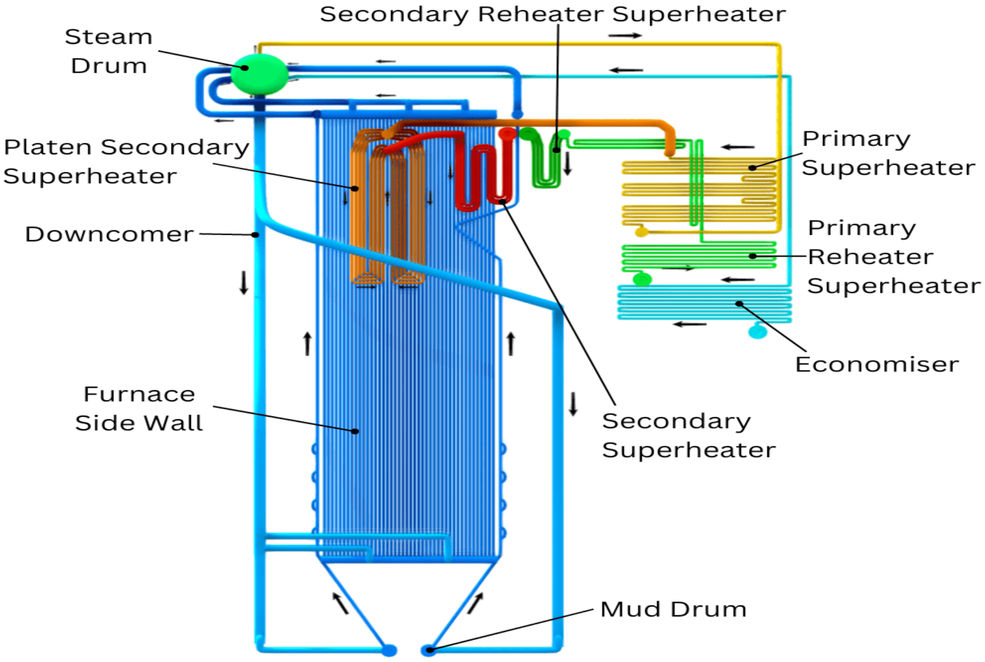


Figure 2.2: Water tube Boiler piping and flow parts

Source: (Savree, 2024)

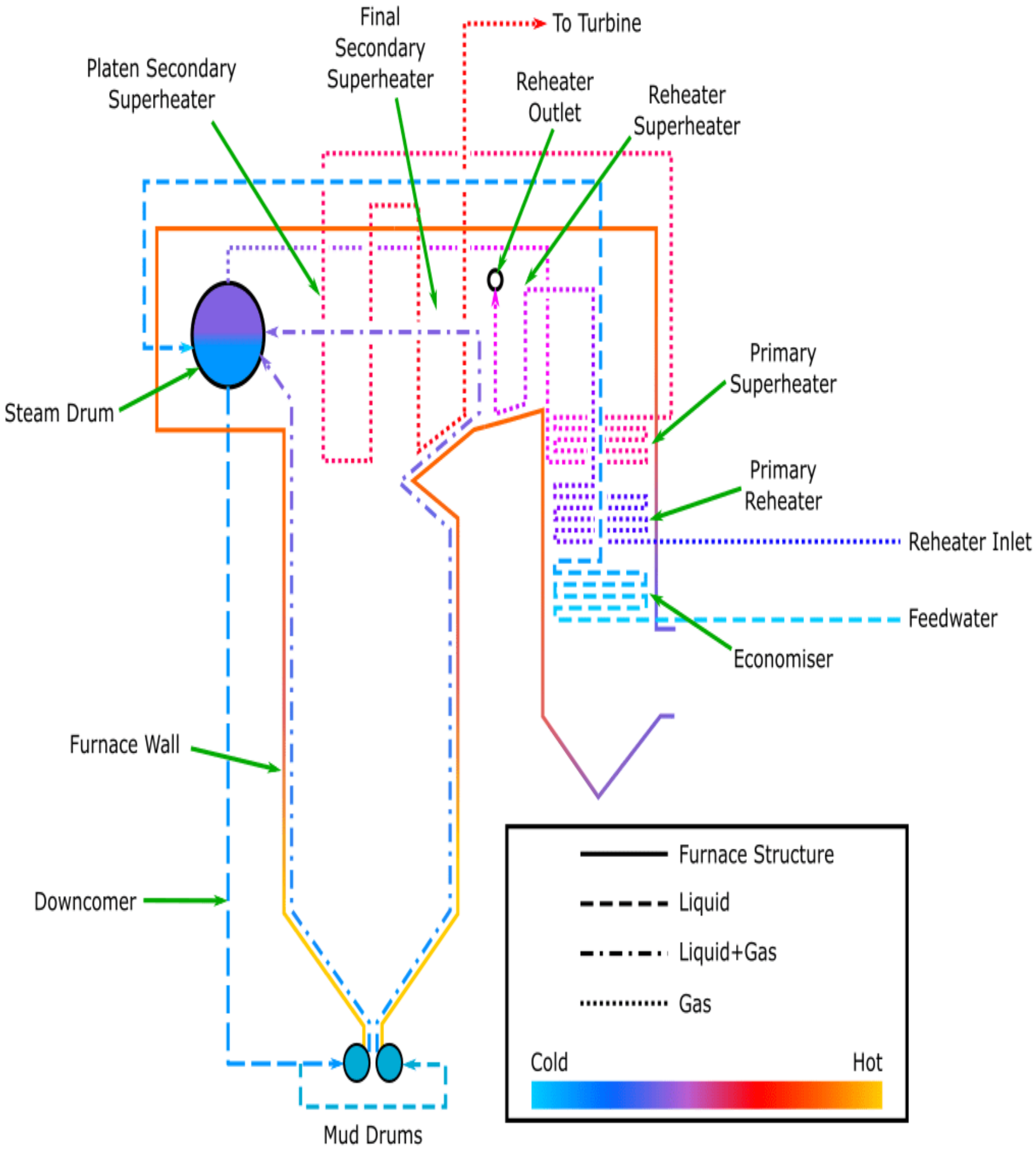


Figure 2.3: Flow Through a water tube boiler

Source: (Savree, 2024)

Figure 2.2 & 2.3 provides schematic representations of water tube boilers, they focus on their superheater and reheater sections.

Figure 2.2 provides a cross-sectional view. Rayaprolu (2013), gives the functions and the detail overview, of the water tube boiler's secondary superheater and reheater arrangement. The key aspects include:

i. Steam Drum: This is where steam is collected before entering superheaters
ii. Platen Secondary Superheater: The first stage of superheating, as water leaves the steam drums
iii. Secondary Reheater Superheater: Steam gets here after initial superheating, for further heating
iv. Downcomer: Tubes that bring water down from the steam drum
v. Furnace Side Wall: This is where combustion occurs directly to heat the tubes
vi. Mud Drum: Collects impurities and allows blowdown. This is located at the very bottom

Figure 2.3 provides a more detailed representation. As described by Tier (2003), the functions and emphasis on the flow paths are described.

i. Steam Drum: This is the central component where water and steam are separated
ii. Platen Secondary Superheater and Final Secondary Superheater: Multi-stage superheating process, where water is heated at different levels
iii. Reheater Outlet: Where reheated steam exits to the turbine, or the source of use
iv. Furnace Wall and Downcomer: Similar to figure 2.2, water is brought down and heated as well
v. Mud Drums: Located at the bottom for impurity collection

Figures 2.2 & 2.3 give an illustration of the complex path that water and steam take in a water tube boiler. Water from the mud drums rises through the furnace wall tubes, turning into steam in the steam drum. The steam then passes through multiple superheaters stages the platen & final secondary to increase its temperature and energy content. In some cases, steam that has already gone through the high-pressure turbine is sent back to the boiler's reheater section for additional heating before going to an intermediate or low-pressure turbine (Basu & Debnath, 2019).

2.2.2.1 Economizer

This is the point through which boiler feed water enters the system. The economizer is a serpentine-type heat exchange in which the boiler water flows back and forth through the coils until it reaches the top of the heat exchanger and is then released to the steam drum (Lahijani & Eris E, 2018). In hospitality, grade boilers are used effectively by transferring the thermal energy to the feedwater entering the boiler

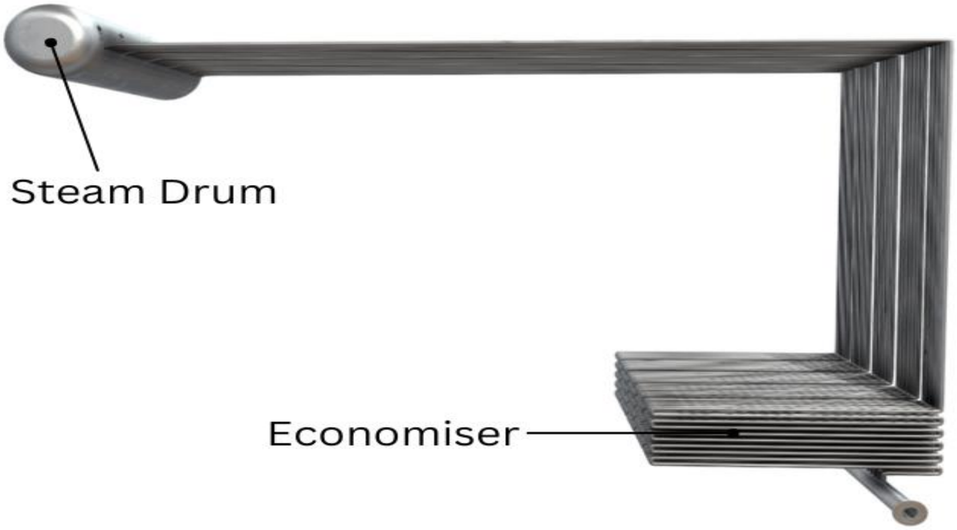


Figure 2.4: Economizer and Steam drum

Source: (Savree, 2024)

2.2.2.2 Steam Drums, Downcomers and Mud Drums

The steam drum is a cylindrical shaped part assembled from flat metal plates. It works to separate water from steam by discharging steam to the steam turbines and recirculating water in the boiler until it turns to steam (Belyakov, 2019). Steam drums are used for drying purposes in industrial applications where dry steam is required. Elgandelwar et al. (2020), observes that steam drums are used together with downcomers, as shown in figure 2.5, to offer pressure regulation and steam desaturation functions in specialized industrial setups that require quality steam.

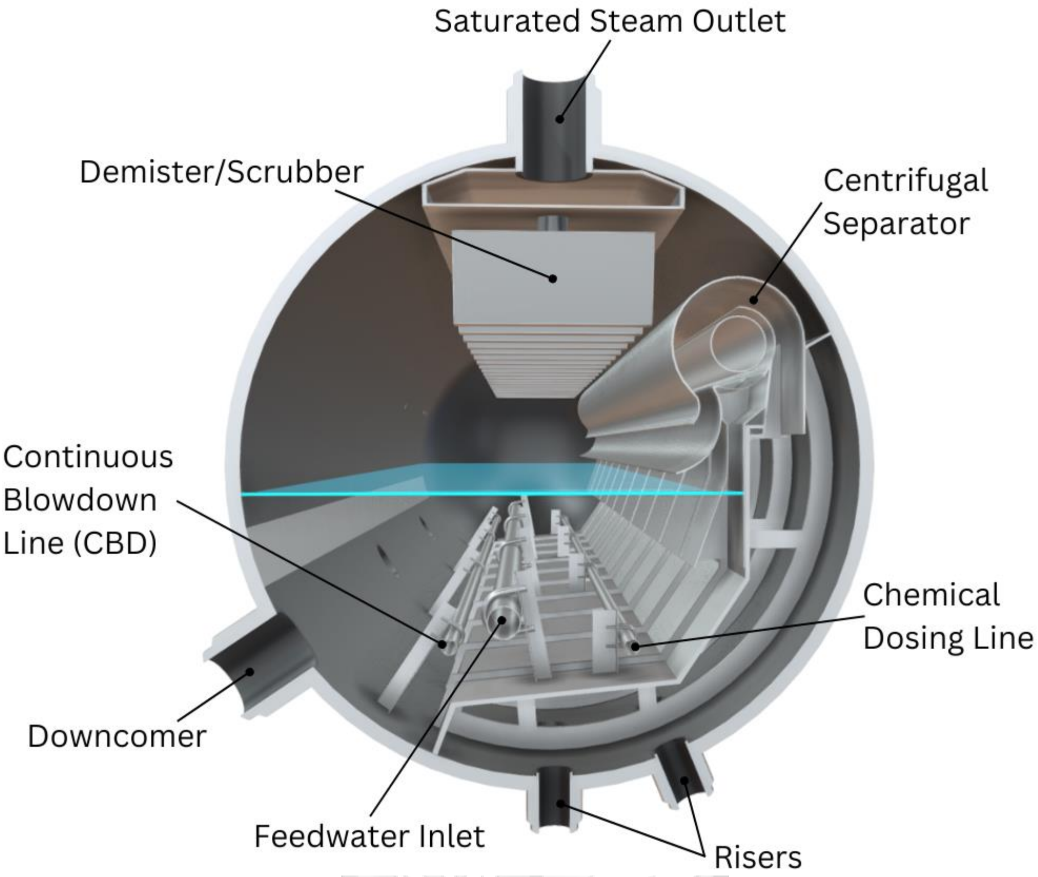


Figure 2.5: Water-tube boiler steam drum.

Source: (Savree, 2024)

Comparatively colder water coming from the steam drum has a higher density, given the temperature is lower, and it flows through the downcomer to the mud drums. The mud drum is a water circulation manifold at the bottom of the Boiler. The boiler operates by natural circulation method, in this case the steam at the top of the boiler while the mud drum is connected at the base by the downcomers. A study conducted by Deghal Cheridi et al. (2019) notes that the primary function of mud drums is to act as a settling chamber for impurities and sediments present in the boiler water. This application is vital where the volumes of usage is high, more so in hotel applications. It can also be used for blowdown processes in special systems to keep levels of impurities in a controlled level and prevent corrosion. In special occasions, a centrifugal pump that is multi-staged is installed between the steam drum and mud drum for the function of forced circulation, as depicted in the figure 2.6.

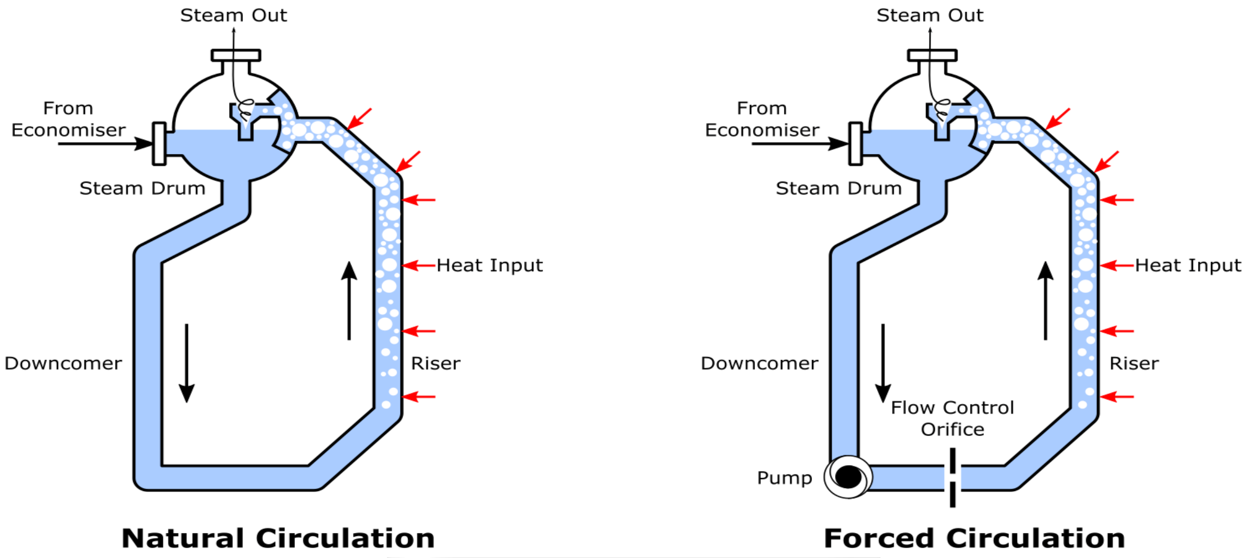


Figure 2.6: Natural circulation and forced circulation.

Source: (Savree, 2024)

A water boiler usually has six downcomers to ensure enough water follows the mud drums, as shown in figure 2.7. These mud drums are fitted at the underneath of the furnace walls, and their role is to collect sediment and other impurities that go through the system (Elgandelwar, Jha, & Lele, 2020).

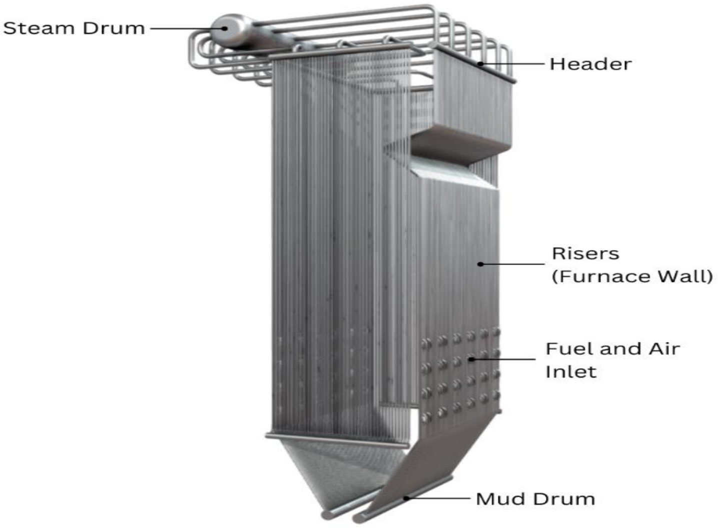


Figure 2.7: Water tube Boiler Mud Drums

Source: (Savree, 2024)

2.2.2.3 Furnace Walls and Risers

After going through the mud drums, the water flows upwards into the tubes adjacent to the furnace. Figure 2.8 illustrates the tubes which are known as risers. These tubes are termed as risers since, through them, the water rises to the steam drum. Risers on all four sides surround the furnace to create a rectangular shape of the furnace, for maximum heat exchange (Md Naim Hossain & Ghosh, 2023). Each side of the Boiler is called a water wall because the risers are full of water.

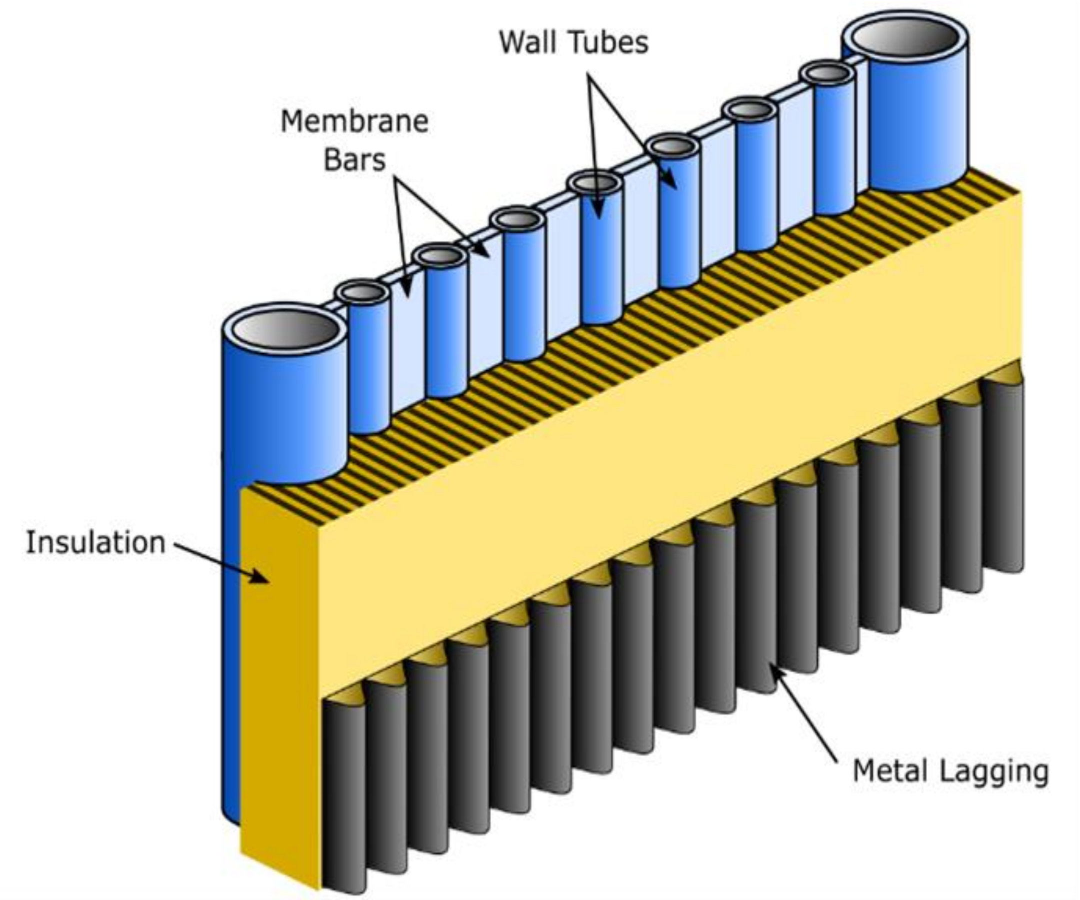


Figure 2.8: Water tube Boiler furnace wall

Source: (Savree, 2024)

These risers have smaller diameters than downcomers since they are supposed to absorb heat. The size also facilitates a larger contact surface area with the furnace (Md Naim Hossain & Ghosh, 2023). The riser tubes, originating from the evaporator section of the boiler, facilitate the phase transition of water to steam, as evaporation occurs within these tubes. Figure 2.9 gives a look at the internal cross-section of a riser

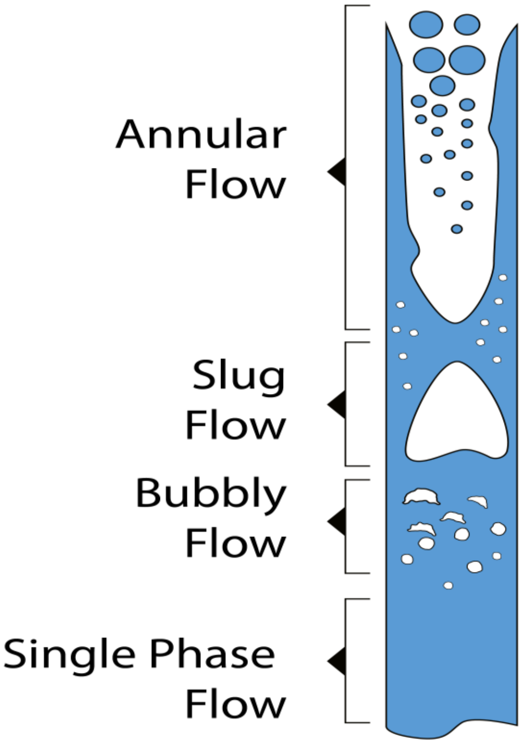


Figure 2.9: Riser tubes

Source: (Savree, 2024)

When there is combustion in the furnace, the heat is transferred directly to the risers through convection and radiation. Md Naim Hossain and Ghosh, (2023) acknowledges that for radiant heat transfer to occur, there needs to be a link of sight between the heat source and the receiver. For this reason, parts such as the economizer do not get heated through radiant heat.

2.2.2.4 Headers and Steam Formation

When water moves up via the boiler furnace wall, it absorbs heat and starts to evaporate. Wet steam is discharged from the top of the furnace to the headers and then to the steam drum. Each furnace has a single header. Deghal Cheridi et al. (2019), notes that in this process, depending on the size of the steam system, not all water evaporates into steam and a portion of it is returned to the steam drum. In figure 2.10, the steam drum, cyclones, scrubbers and baffles separate suspended water molecules from the steam. Dry saturated steam is discharged only from the stream drum to protect downstream equipment from damage caused by moisture. The process also allows minimizing pressure drops and ensuring efficient steam utilization throughout the system.

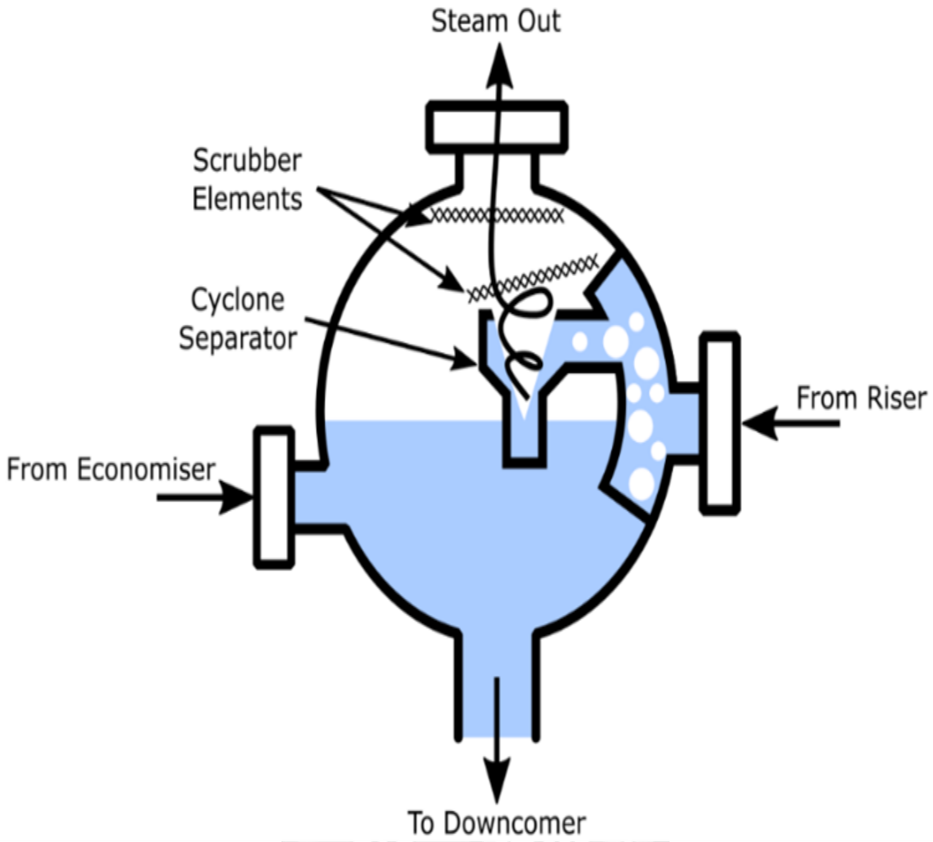


Figure 2.10: Water tube Boiler steam Drum parts.

Source: (Savree, 2024)

2.2.2.5 Superheaters

The temperature and pressure output of the steam determine the amount of energy sent to the steam turbine, or the end use appliance. To increase steam temperature and pressure, the steam is passed through a series of superheaters. Here, steam is heated to above its saturation temperature. Superheaters are designed in the same way as risers and can be classified as primary or secondary depending on where they are installed in the Boiler. The work of a primary superheater is to add heat to the steam as it passes through a comparatively colder area of the Boiler (Elgandelwar, Jha, & Lele, 2020). This process averts the steam from cooling and condensing before reaching the secondary superheaters. In essence, dry saturated steam moves into the primary superheater and comes out as dry superheated steam.

Figure 2.11 illustrates the configuration of the superheaters in an industrial steam generation system.

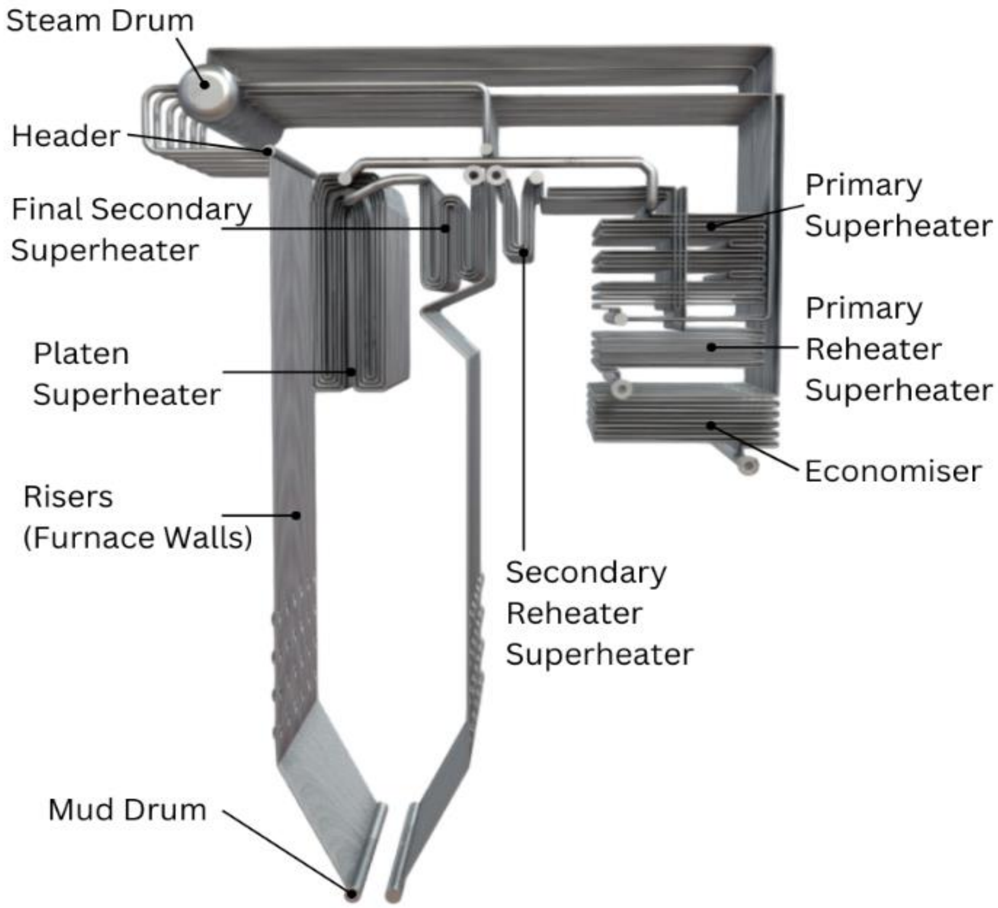


Figure 2.11: Water tube Boiler Primary and secondary superheaters

Source: (Savree, 2024)

Afterward going through the primary superheater, the dry superheated steam goes through the platen superheater and then the final secondary superheater. These superheaters are situated in the hotter regions of the boiler to ensure the steam attains its uppermost temperature before going to the high-pressure stream turbines. After this process, the flow can only proceed by passing through the reheat boiler.

The key downsides of using a water-tube boiler for steam generation are its complex design and the need for a highly skilled operator (Shokri & Mahdi, 2023). It also has high maintenance costs. More importantly, it is more economical for larger power plants and unsuitable for small industries. Shokri and Sanavi Fard (2023), acknowledge that in the application in the industrial set up, where steam is required at a regulated temperature and pressure. Water-tube boilers are applicable for reliable steam delivery and system efficiency.

2.2.3 Fire-Tube Boiler

Fire-tube boiler has fire tubes or the furnace immersed in water unlike the water-tube boiler. This makes the hot flue gases generated during combustion flow through the fire tubes (Brodowicz, 2024). Hot flue gases transferred heat to the surrounding water through conduction, as shown in figure 2.12.

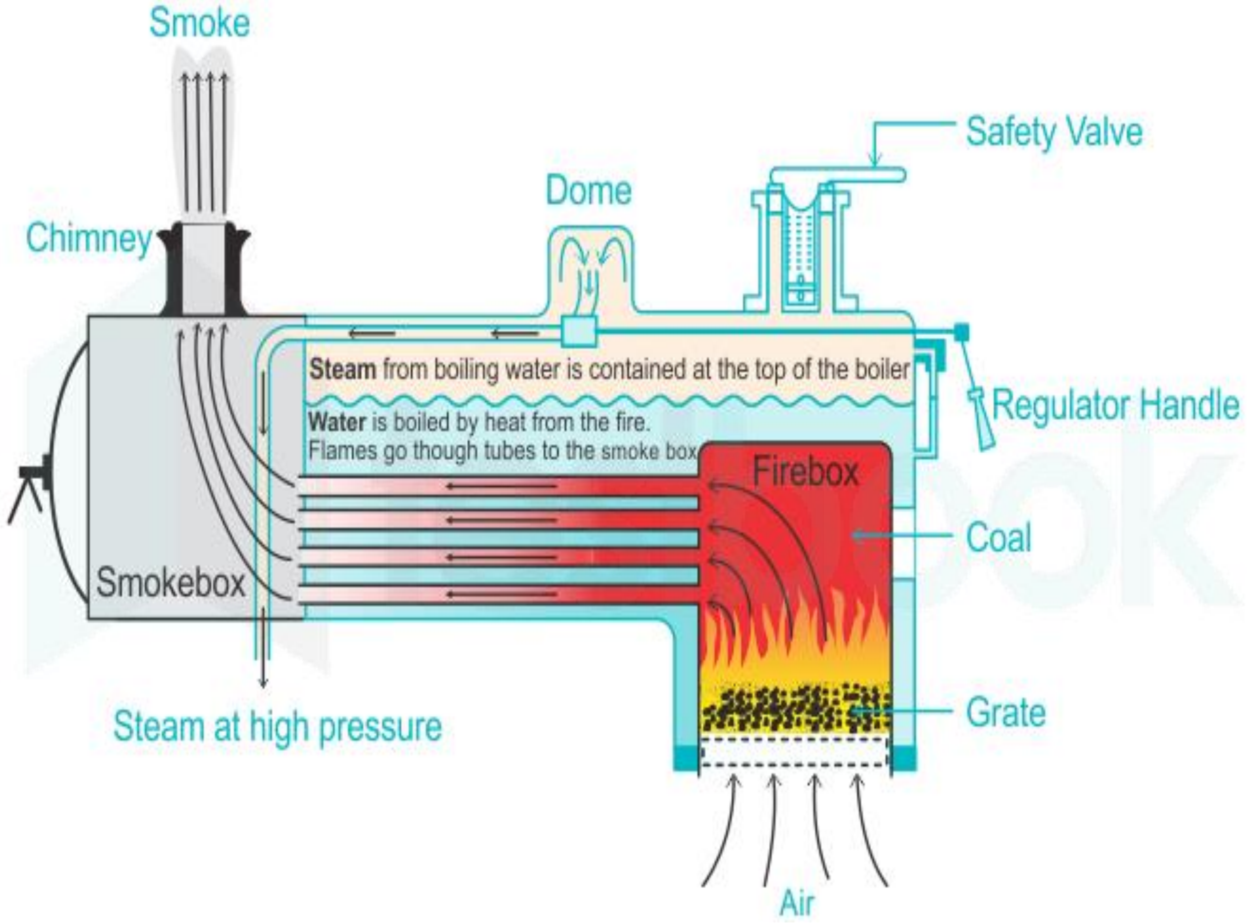


Figure 2.12: Basic Firetube boiler structure

Source: (Industrial Quick Search, 2023)

Firetube boilers are common in low to medium-steam pressure applications and small-scale steam generation operations. A typical firetube boiler has a furnace combustion chamber, grater, firetubes, chimney and smokebox. The discharge waste gases and smoke into the atmosphere, is extracted through the chimney (Abbas, Uzair , Khan , & Hussain, 2020) . Fire tube boilers can use diverse fuel sources, including coal and solid or liquid fuels.

Firetube boilers function similarly to water tube boilers, with variations on their design and heat transfer processes. The operation begins with a feed pump that feeds water into the boiler system. Combustion is initiated when fuel is placed on a grate within the furnace and ignited through a fire hole. The combustion process generates heat, which is transferred to the flue gases, raising their temperature (Abbas, Uzair , Khan , & Hussain, 2020).

The heated flue gases then flow into the combustion chamber before entering the fire tubes. As these tubes are fully immersed in water, they facilitate heat transfer through conduction, leading to a progressive increase in water temperature. This thermal energy starts a phase transformation, producing saturated steam. Depending on the operational requirements, the saturated steam can either be utilized directly or subjected to further heating to generate superheated steam, enhancing efficiency and energy output.

There are about five types of fire tube boilers, depending on the application process one is using.

2.2.3.1 Cochran Boiler

This is a low-pressure, internally fired, and vertical drum air boiler. It is an adapted type of the simple vertical Boiler, making it portable and can used in small industries and power plants. Elkelawy et al. (2022) observes that the most common source of fuel used in Cochran boiler is oil, coal or woody biomass.

This specific boiler functions on the principle of convection, featuring a cylinder-shaped shell with a heater at the base and multiple fire tubes running through it longitudinally. Shown in figure 2.13, fuel typically coal is combusted in the furnace, generating burning gases that pass through these fire tubes. The heat is shifted to the surrounding water, where water is heated up and converted into steam. The steam rises into the steam dome above. Abbas et al., (2020) appreciates that due to the high operation pressure and temperatures, safety features such as safety valves, water level indicators, and pressure gauges are used to ensure safe operation. The chimney provides a natural draft for the expulsion of flue gases while simultaneously drawing in fresh air for combustion, creating a continuous convection-driven airflow that enhances combustion efficiency. This design ensures a simple and efficient design that makes the boiler suitable for small to medium-sized industrial applications, where steam is needed for various processes.

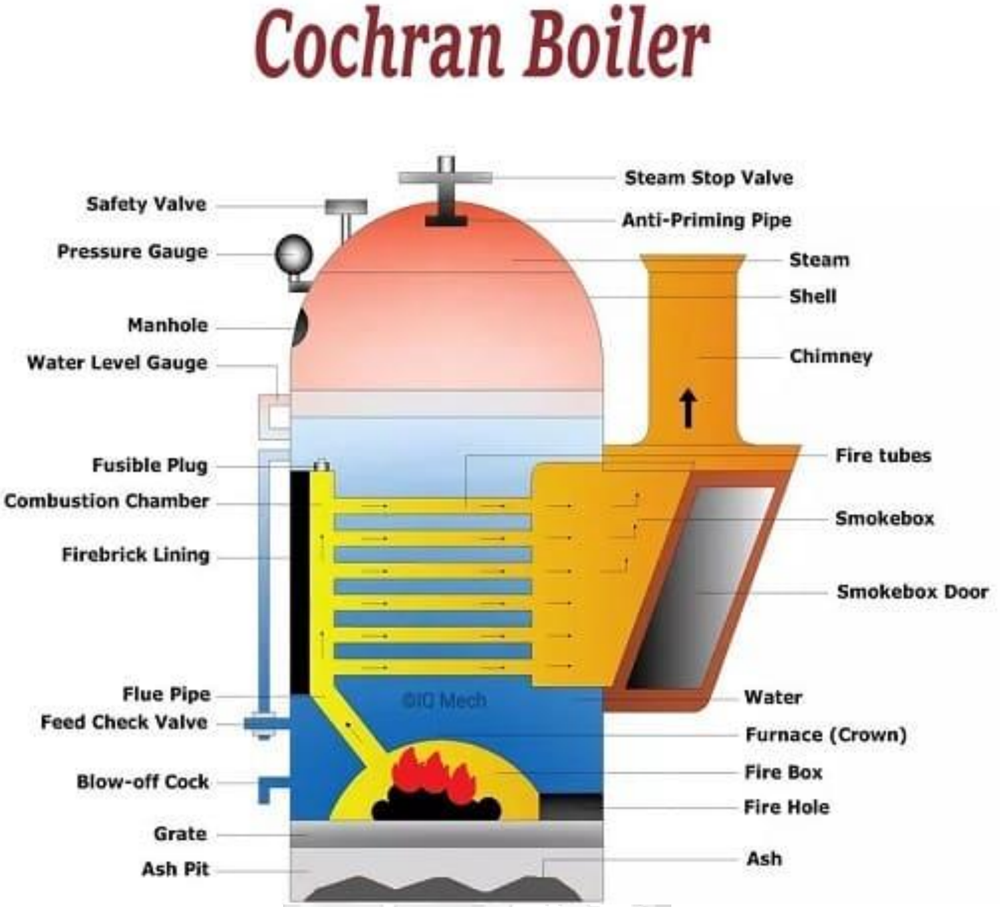


Figure 2.13: Cochran Boiler

Source: (Boiler learn, 2023)

2.2.3.2 Cornish Boiler

This type of boiler is more advanced than the Cochran broiler regarding steam production volume, despite its small size and portability. The Cornish Boiler characteristically has a case with a length between 4m and 7m and a 1.2m and 1.8m diameter. The Boiler has only one fire tube, from the bottom of the boiler that branches to several before exiting through the chimney. Its key advantages are the simple design, low maintenance cost, and portability (Er Amrit, 2021). It is mainly used in small hydropower plants, sugar mills and the chemical industry.

This type of boiler works by burning fuel in a furnace located at one end of a cylindrical shell, as shown in figure 2.14. As the fuel burns, the heat is simultaneously conducted through the furnace walls and into the water stored within the boiler. The water heats up and converts into steam.

Because of its circular nature, the steam upsurges to the topmost of the boiler and collects in a steam dome or chamber, depending on the specific type. The steam is momentarily drawn off for use in various applications in industry or hospitality processes. Mohd & Mohammad (2023), notes that to sustain a steady supply of steam, the water level inside the boiler is carefully controlled using safety values and stop valves. Safety features such as pressure relief valves and blow off cocks are also incorporated to prevent the boiler from exceeding safe pressure limits.

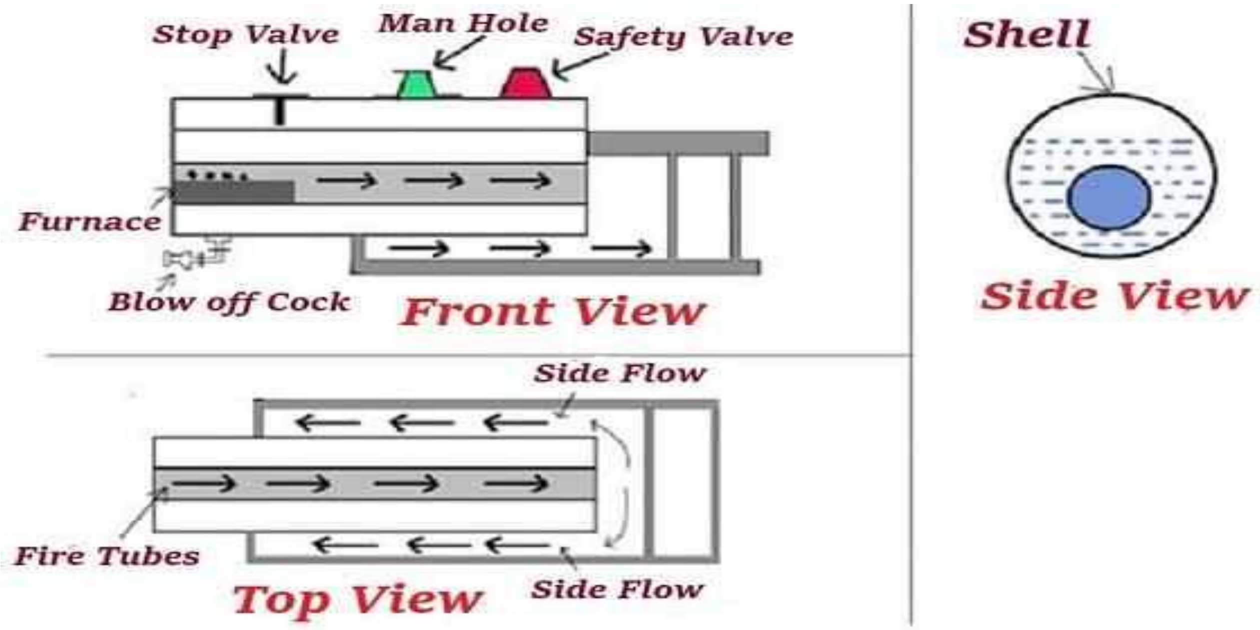


Figure 2.14: Cornish Boiler

Source: (Er Amrit, 2021)

2.2.3.3 Locomotive Boiler

This is a horizontal axis drum that is externally fired, multiple tubes and a large fire space. Even though it is relatively more complex in terms of design than the previous two, it is also portable. The locomotive boiler parts have a furnace, grate, feed pump, ashpit, chimney, firetubes and smokebox. As shown in figure 2.15, solid coal is placed in a grate, while an ashpit collects the burnt fuel. These boilers were commonly used in locomotive engines but have been replaced today by electricity or diesel fuel (Elkelawy, 2022). Their main advantage is a high production rate of steam generation. However, their downside is low overall efficacy. The main fuel used was woody biomass and coal. The locomotive boiler was efficient in use because of the high volume of steam that it could produce.

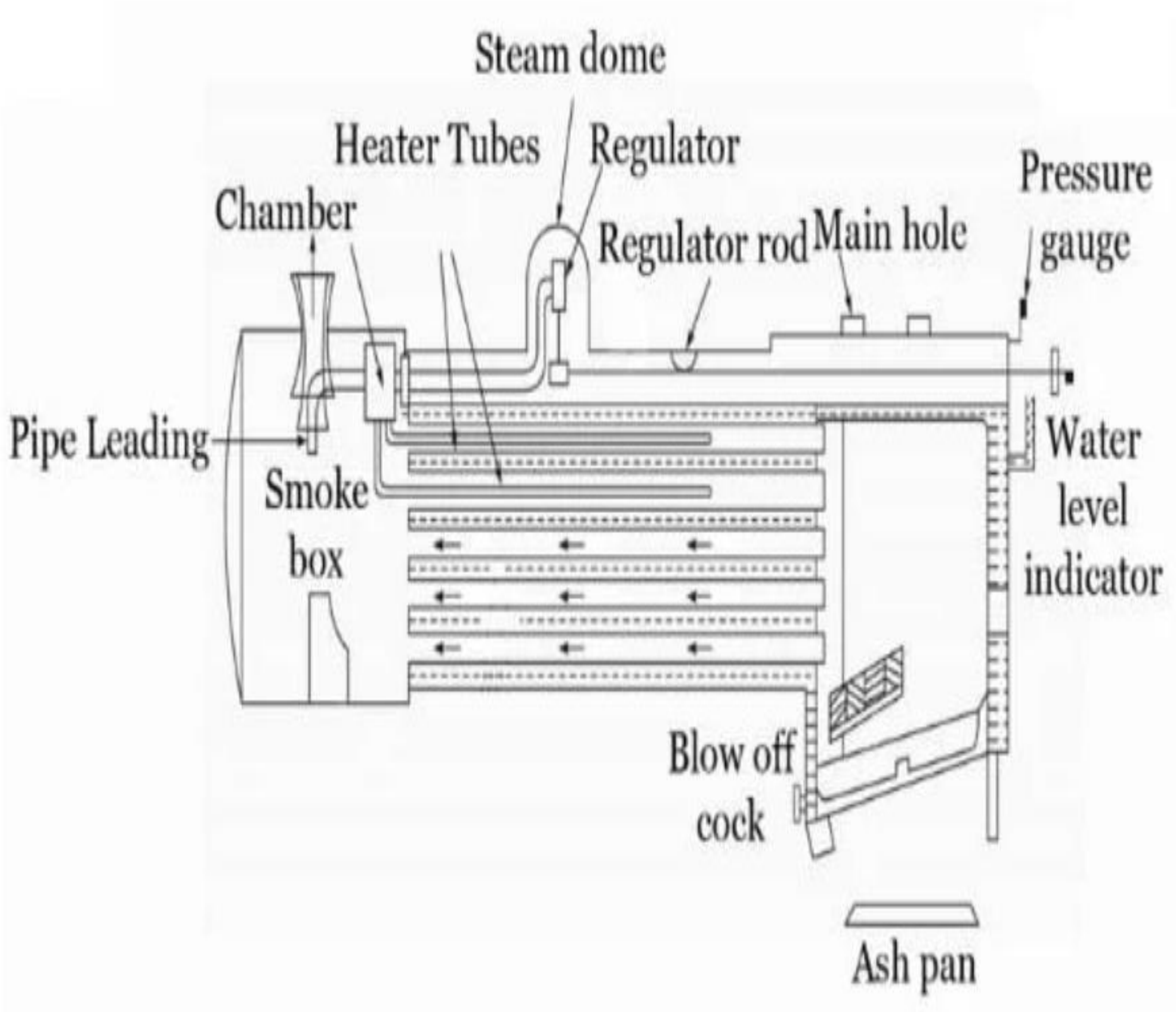


Figure 2.15: locomotive broiler

Source: (Kumar, 2020)

2.2.3.4 Horizontal Return Tubular Boiler (HRT)

Horizontal return tabular boiler has a horizontal cylinder-shaped shell with several flue tubes aligned horizontally. It has low initial cost, easy installation and versatility in fuel sources, as it can operate using wood, coal, oil or gas (Md Naim Hossain & Ghosh, 2023). Fuel is burned in a fire box, shown in the figure 2.16, and flue gas travels through the submerged flue tubes in water. The fuel gas heat the water through conduction, the saturated steam generated is raised and collected in the steam dom and evacuated for use.

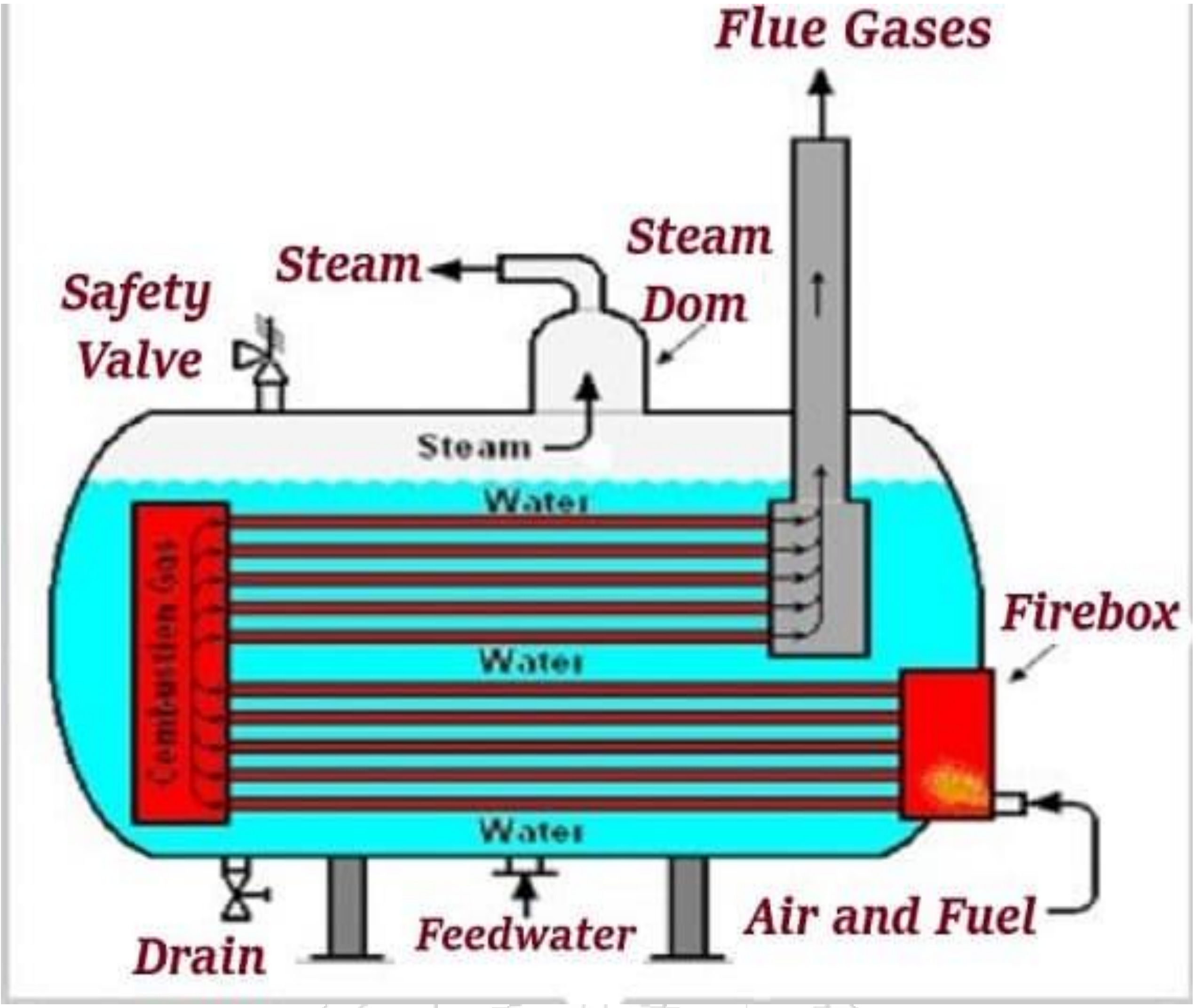


Figure 2.16: Horizontal Return Boiler

Source: (Mechanical Engineering, 2016)

2.2.3.5 Lancashire Boiler

It works in a similar way as the Cornish Boiler. The difference is that it has two additional flues with fires. The Lancashire boiler has a natural circulation method and is internally fired. Its key advantage is the higher thermal efficiency of over 80% and a working pressure of up to 16 bar. Given its natural circulation system, it consumes very little electricity or other fuel sources (Elkelawy, 2022). This particular kind of boiler is commonly operated in sugar making, paper, tire, and textile industries. The additional flue tubes as illustrated in figure 2.17 makes the boiler versatile to use the applicable source of fuel in a local area.

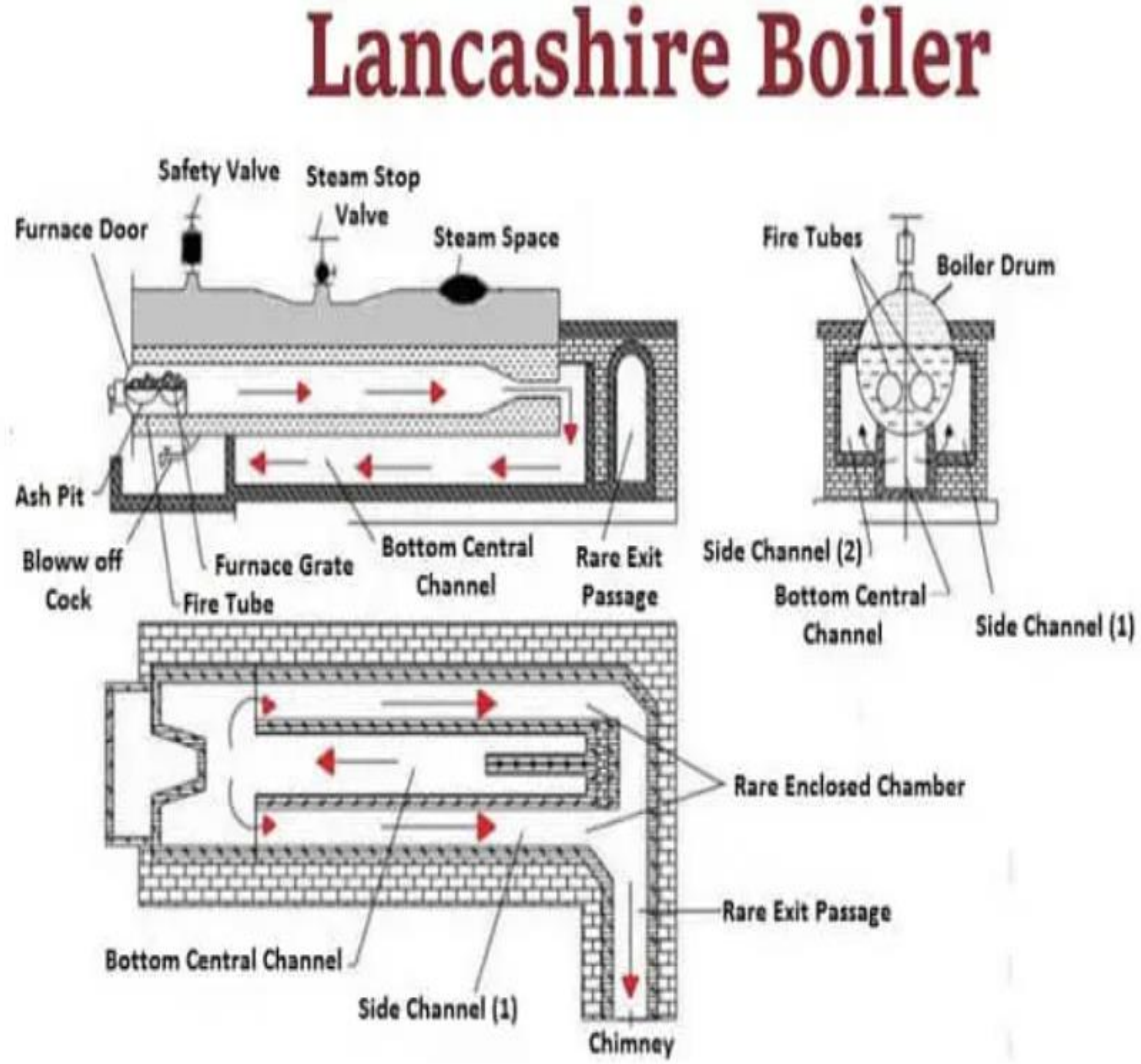


Figure 2.17: Lancashire Boiler.

Source: (Thermodyne Engineering Systems, 2017)

2.2.3.6 Simple Vertical Boiler

A vertical type of boiler is installed in the vertical direction; however, it does not remain stationary like other fire tube broilers. A simple vertical boiler with a diminutive steam production rate is best used in low steam generation usage. Its distinguishing feature includes its small size and requires installation space. It also has a low installation cost, making it an economical choice for various applications. Due to its compact design and efficient steam generation, it is commonly used in steam lorries, railway engines, and cranes, where reliable and consistent steam supply is essential for operation.

The key benefits of a fire tube boiler are simple maintenance and cleaning, versability in terms of simple operation, and relatively more compact in construction. Elkelaway (2022), acknowledges that the downsides of the firetube boilers are the incapability of producing high pressure, inappropriate for high rates of steam demand, and generally lower thermal efficiency compared to water tube boilers.

2.2.3.7 Steam Use

Steam has ideal properties that make it applicable in wide industrial applications. The main use is power generation, in which steam drives turbines and generates electricity. In the food, chemical, and textile industries, steam plays a crucial role in process heating, fabric curing, distillation, and pasteurization. In pulp and wood industries, steam is used in drying processes in wood processing, similarly in the pharmaceutical industries for drying of the medicine in production. Steam is used for sterilization purposes where hospital facilities sterilize surgical equipment and process plant sterilize canning equipment and surfaces.

In spas and saunas, steam is used to create a controlled environment of heat and humidity, which enhances relaxation, hence used for relaxation purposes. In large hotels with high operational demands, steam is for general cleaning and disinfecting surfaces. In Laundry process, specifically, where large industrial laundry equipment such as calendar machines and linen dryers are used, rely on steam for efficient drying, pressing, and sterilization, ensuring that large volumes of linens and textiles are processed effectively while maintaining high sanitation standards. Steam is also used in the kitchen area for food preparation by direct steaming and for cleaning and sanitation purposes.

2.2.4 Municipal Solid Waste

Municipal solid waste denotes to the waste-away generated by residences, enterprises and organizations. It consists of materials that are commonly wasted by civilization, such as paper, plastic, food waste, glass, metals, and textiles. Figure 2.18 shows, in a graphical way, the various MSW generation sources and the subsequent management process including waste-to-energy conversion as one of the key methods. Waste in this case is used as a primary fuel in heat intensive process.

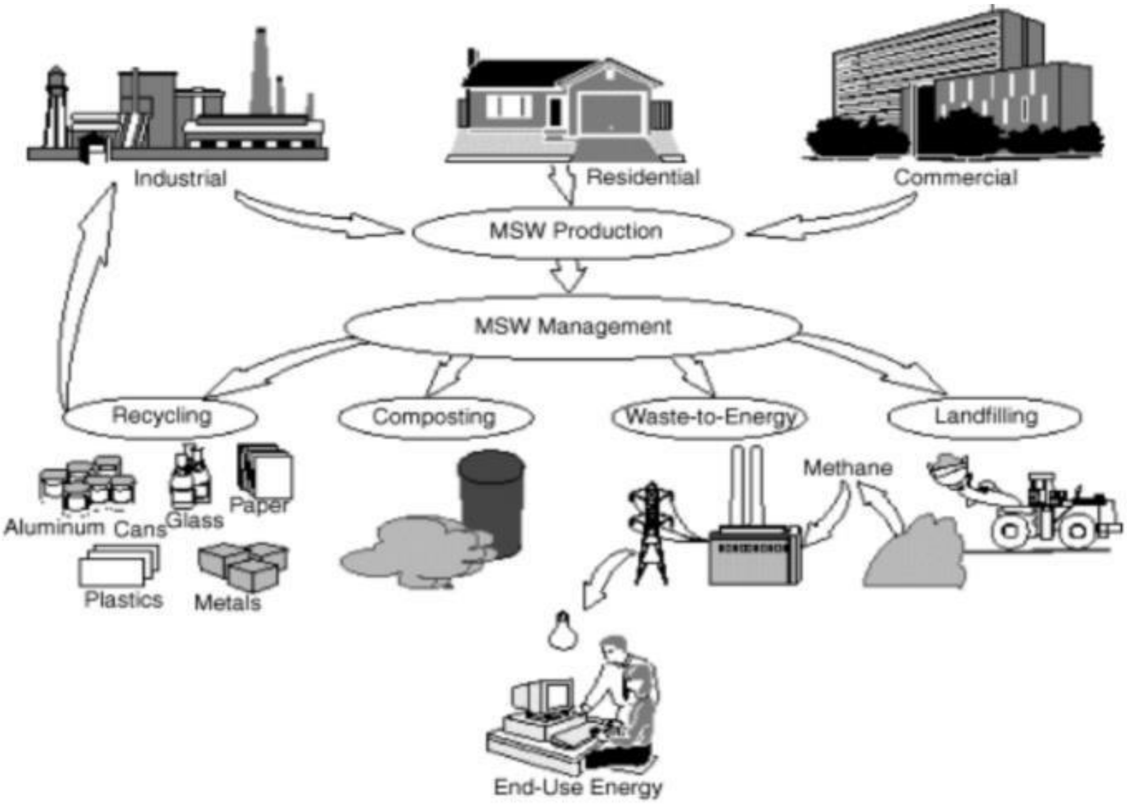


Figure 2.18: Different sources of MSW and management process after.

Source: (Goyal, et al., 2017)

MSW may be divided into a variety of kinds, such as industrial, hazardous, and biological waste, each needing a unique set of handling techniques. Population density, consumer habits, urbanization, and economic activity all have an impact on the rate of waste production.

The final treatment or disposal of waste materials is referred to as waste disposal. Landfilling, incineration, recycling, and composting are common disposal strategies. The kind of trash, environmental requirements, cost-effectiveness, and accessible technology are only a few examples of the variables that affect the choice of disposal techniques.

2.2.4.1 Waste Characterization

Waste properties vary depending on the type of waste disposed of, which directly influences its characterization. Woldegerbriel & Amona (2022) observes that for proper characterization of materials in MSW, one needs identification of moisture, ash, and calorific values. Yazdani et al. (2020) notes that municipal waste is non-homogeneous source of energy that diverges significantly from traditional fossil fuels. Waste characterization is a crucial step in waste management and waste-to-energy projects as it provides essential data for designing effective waste-to-energy strategies, selecting appropriate treatment technologies, and evaluating the capacity for resource retrieval from waste. Waste amassed in well-to-do areas is characteristically less dense as it holds less packaging and lighter materials and less ash and food Waste (Yazdani, Salimipour, & Moghaddam, 2020)

The process of characterizing waste streams is continual since consumption patterns, waste creation rates, and waste energy techniques might change over time. Table 2.1 shows a typical waste aggregation and the common wastes. The effectiveness of waste energy recovery techniques is regularly checked to make sure they are still in line with the latest trends in waste composition.

Table 2.1 Various common municipal waste aggregation sources and their common wastes

	Measurement (wt. %)	Range	Typical
Residential	Food waste (mixed)	50-80	70
	Paper	4-10	6
	Plastics	1-4	2
	Yard wastes	30-80	60
	Glass	1-4	2
Commercial	Food wastes	50-80	70
	Rubbish (mixed)	10-25	15
Construction and demolition	Mixed demolition	4-15	8
	Combustibles	-	-
	Mixed construction Combustibles	4-15	8
Industrial	Chemical sludge	75-99	80
	Sawdust	10-40	20
	Wood (mixed)	30-60	35
Agricultural	Mixed agricultural waste	40-80	50
	Manure (wet)	75-96	94

Table 2.2: Waste sources aggregation and their proximate analysis values

Typical proximate analysis values (% by weight)				
Types of waste	**Moisture**	**Volatiles**	**Carbon**	**Ash**
Mixed food	70.0	21.4	3.6	5.0
Mixed paper	10.	75.9	8.4	5.4
Mixed plastics	0.2	95.8	2.0	2.0
Yard wastes	60.0	30.0	9.5	0.5
Glass	2.0	-	-	96.99
Residential MSW	21.0	52.0	7.0	20.0

Different wastes have different calorific values. Mitali et al. (2022) notes that calorific values refer to the quantity of heat energy discharged when a given amount of a substance undergoes complete combustion without reliance on a secondary fuel. Table 2.2 show the average aggregation and proximate values of municipal solid waste. Proximate analysis refers to the method used to understand the basic composition of the waste (Ndagi, et al., 2023). In this analysis, moisture content (MC), volatile matter (VM), ash content and fixed carbon (FC) are evaluated in the composition of the waste. Woldegerbriel & Amona (2022), describes moisture content as the fraction of water in the waste, volatile matter as the percentage of organic materials like food scraps, paper, and textiles that vaporize during heating process. Ash content is the percentage of inorganic material remaining after burning the volatile matter. It includes things like glass, metal, and mineral components, which generally require higher temperatures to combust. Fixed carbon is the non-volatile portion of the organic matter that leaves behind a solid residue after heating.

Figure 2.3 gives quantifications of various waste calorific values. The ash and water content will affect the residual material in the full combustion of the waste.

Table 2.3: Calorific values of different materials

Material	**Calorific Value (BTU/Ib.)**	**Ash Content (wt.%)**	**Moisture Content (wt.%)**
Softwood	6330	0.1	19
Fiberboard (90% paper)	7600	4.6	7.5
Damp wood	5690	1.2	27.5
Leather trimmings	7670	5.2	10.4
Cotton seed hulls	10600	2.47	8.9
Sludge material (steel mill)	9150	24.5	1.9
Nitrile rubber	15240	3.4	-
Cardboard granulated	8592	12.3	6.4
Carbon residue	13681	8.7	Nil
Wood waste, sawdust	7500	0.8	14
Nutshells	7980	1.75	11.85

This research will use municipal waste as the feedstock to assess its viability in steam generation. Ivanov et al. (2024) suggests that in using MSW as fuel, one needs to check on quality by looking at the characteristic component, water content (%W), ash content (%A), and combustible content. (%C).

Based on various characteristic components of waste materials, waste-to-energy pathways provide a form of a viable way to use waste as feedstock in power generation and steam generation. Different technologies will be applicable based on the energy conversion process and the available waste material. Approaches to various technologies can be made by incineration, gasification, and anaerobic digestion. This research will focus on incineration via boilers in steam generation.

2.2.5 Waste Generation in Nairobi

Studies such as that of Gilbert et al. (2022) highlight the lack of an efficient solid waste collection or management system. This is backed up by Haregu et al. (2017) who pinpoints that more than half the daily waste generated in Nairobi is not collected, making it hard to account for. According to the data compiled by the Kenya National Bureau of Statistics Economic Survey (2022), the quantity of solid waste produced in Nairobi city county had proliferated by 17% from 1.97 million tonnes in 2020 to 2.30 million tonnes in 2021.

Data compiled by Kimata et al. (2019) while echoing the increasing urbanization, without adequate disposal suites and transportation, has made garbage collection within Nairobi city extremely poor.

The report highlights that many areas within the city remain unserved, and most garbage is dumped in the open and remains unaccounted for. The report also provides trends in waste generation in Nairobi between 1973 and 2015. Based on the available data as of 2017 as shown in table 2.4, the daily waste production in Nairobi is estimated to be 3,000 tonnes, while in 2022, this figure has risen to more than 4,000 tonnes daily. Notably, it had been projected that the daily waste production would hit about 3990 tonnes by 2030, and as of 2023, the daily production has gone beyond the projection. Considering the population growth rate and changing consumption and lifestyle trends among the urban population, the projection of future waste production remains complex and nonlinear. Nonetheless, by 2030, Kenya's municipal solid waste is projected to double as urbanization accelerates, with 50% of the population expected to reside in urban areas ((World Bank, 2018))

Table 2.4: Trends in waste production in Nairobi City

Year	Daily production (tonnes)	Monthly (tonnes)	Annual (tonnes)	Average (Annual growth rate)
1973	452.66	13,579.80	162,957.60	-
1975	501.92	15,559.52	186,714.24	4.86
1985	850.86	25,525.80	306,309.60	6.35
1998	1,426.00	42,780	513,360	3.7
2002	1,530.00	45,900	550,800	1.81
2004	2,347.00	70,410	844,920	26.81
2015	2,679.89	80,396.70	964,760.40	1.3
2017	3,000.00	90,000	1,080,000	6.09
2020	5,397.81	161,934.30	1,970,000.00	27.76
2021	6,657.53	199,725.90	2,300,000.00	16.75

Source: Gilbert et al. (2022); Haregu et al. (2017); Kimata et al. (2019)

Based on the compiled trends in waste production in Nairobi city, the annual growth rate is not linear. However, based on the result, the estimated waste production in 2030 would be over 5.81 million tonnes annually.

2.2.5.1 Types of Waste Produced

There is a limited detailed compilation of the type of waste produced in Nairobi city. The lack of proper waste collection and management systems can account for that. The data compiled by Mugo (2019), summarizes the types of waste produced in Nairobi in table 2.5 Below.

Table 2.5: Types of waste produced

Waste type	Retail shop	workplace	Office and Institutions	Hotels	Business Waste areas	collection points adjacent to markets	Average
Organic	43.6	25.9	48.9	69.2	36.4	51.3	45.9
Paper	22	42.1	19.8	10.2	18.9	11.1	20.7
Plastics	19.8	17.1	10.9	8.7	14.3	14.3	14.2
Glass	2.3	0	3.7	1.4	5.5	3.1	2.7
Metal	2.1	0.8	2.7	1.6	3.4	2.2	2.1
Other	10.2	14	14	8.9	21.5	18	14.4

Source: Mugo (2019)

2.2.6 Combustion Characteristics

Combustion is the chemical reaction between oxygen and fuel to release heat and light. Incineration refers to the controlled combustion; in this case, controlled combustion of waste materials. Combustion infuses incineration but provides the heat needed to break down and reduce the volume of burned waste (Kiang, 2018). In this case, the waste is used as fuel, and controlled burning occurs in the optimized environment, such as a boiler, which ascertains complete combustion while minimizing smoke and other harmful byproducts.

While burning waste for heat generation, higher and low heating values emerge as critical factors to consider. Higher heating values assume all the water vapor produced in the combustion process is condensed back to liquid water and releases the latent heat. Whereas lower heating values assume the water vapor, it remains as vapor, and no latent heat is produced. Practically, capturing all the water vapor from flue gases is hard and energy-intensive; therefore, lower heating values tend to be the most commonly used (Jisu, Lee, Kyuyeon, Jun-gu, & Taewan, 2024). A good example is wood, which has a higher heating value of 20MJ/Kg burn if burned in a boiler, would produce about 17MJ/Kg ((Bridgwater, 2012).

According to Oludolapo and Moses (2019), municipal solid waste characteristics play a significant role in combustion and generating heat. The scholars elaborate that the constitute of the waste and its elements are very much an influence in a country's progress and prosperity. A report by Filip & Niko (2013), follows a difference in waste characteristics between developed and developing countries. This is because developed nations have a waste structure with more packaging materials (plastic and paper), which tends to have higher calorific value. Developing nations have an average waste structure with less packaging material and lower calorific value. It should be noted that the typical waste quantifiable utilities in the waste energy progression are constituted of elements that add up to the calorific value of the waste. Figure 2.6 summarizes the properties of waste material combustion.

Table 2.6: Properties of waste material combustion

Material combustion properties				
Components	**Moisture**	**Ash (%)**	**Combustibles**	**Heating value (MJ/Kg)**
Textile	7.56	5.76	86.68	16.65
Chart board	6.85	11.88	81.27	17.49
Soft paper	23.99	12.43	63.58	12,43
plastic foil	0,51	13,24	86.25	40.14
hard foil	0.4	5.28	94.32	40.12
PET bottles	0.42	0.15	99.43	21.51
Wood	12.52	2.31	85.17	16.32
Styrofoam	1.07	9.98	88.95	27.95

Source: (Kokalj & Samec, 2013)

Based on the summary in table 2.6 above, it can be deduced that waste would be combusted differently depending on its composition. Essentially, cellulose-based materials like textiles, wood, and paper burn quickly, have higher heating values, and readily decompose. At the same time, plastics and rubbers would require higher temperatures to burn, given their complex molecular structure. They also tend to release more pollutants during the burning process. Foot particles can burn readily, but they produce a lot of moisture content and require a lot of drying before combustion. Materials made of metals generally don't burn, but at very high temperatures, they can melt. The particle size also matters as waste with smaller particles has a larger surface area exposed to oxygen and is likely to burn faster (Castells, Tascón, Amez, & Fernandez-Anez, 2023). Waste moisture content also influences the burning rate as high moisture content uses a lot of energy to evaporate water before combustion happens.

Regarding ash production, paper and wood produces residues of potassium, calcium, and magnesium. Conversely, plastics are likely to produce harmful substances based on the type of plastics used. Metal substances tend to remain unchanged and would need separation or recycling (Castells, Tascón, Amez, & Fernandez-Anez, 2023).

2.2.7 Existing Techniques for Modeling Municipal Solid Waste

Modeling municipal solid waste is essential for optimizing waste management strategies, predicting generation rates, and improving sustainability efforts. It follows that models are essential tools for waste mitigation and mitigation strategies, connecting determinants of waste emission to various potential outcomes, including energy generation. Multiple models have been developed and applied in research, policy, and practice for policy implementation and the technical use of municipal waste. Several techniques used to model municipal solid waste in energy generation were identified in this study. With specificity to steam generation, these models are as follows:

2.2.7.1 Statistical and Regression

Statistical and regression models are analytical tools commonly applied to understanding the relationship between variables, predicting outcomes, and assessing trends. The statistical model analyzes the data presented to identify the patterns, test hypotheses, and infer conclusions about the underlying population and the variables present. They are essential for descriptive, diagnostic, and inferential analyses when formulating a policy and making technical decisions. A regression model is a subset of regression models that aim to explain the relationship between dependent and independent variables. The models typically predict the Behavior of a dependent variable, such as MSW generation, based on the variations in one or more independent variables within a given population, such as income and energy consumption.

The regression models vary in complexity depending on the relationship they intend to explain. A case in point is Linear regression, which examines a simple relationship between variables assuming linearity. As for the multiple linear regression (MLR), they extend the simple linear regression approach by incorporating various predictors that allow for a multifactorial understanding of the dependent variable. Nonlinear and polynomial regression, on the other hand, explain more complex relationships.

In the case of MSW, statistical and regression models are crucial for various functions, including forecasting, evaluation of key drivers, and policy development. Beigl et al. (2008) employed a statistical regression model to forecast MSW generation in European cities by analyzing population density and household size. This study highlighted the importance of incorporating socioeconomic factors for accurate waste predictions. This study further demonstrated how regression modeling could guide municipal planning and provide precise estimates of waste quantities. Ceylan (2020) also employed multiple linear regression to predict MSW generation in Chiapas, Mexico. This study assessed the relationship between waste production variables such as income, population density, and urbanization. The study employed techniques like variable screening and multicollinearity tests to enhance model reliability. This work underscored the applicability of regression models in developing localized waste management policies.

2.2.7.2 Dynamic Energy Models

Dynamic energy models incorporate computation frameworks that simulate temporal variation in energy systems by incorporating dynamic variables such as fluctuating waste inputs, weather conditions, system behaviors, and operational strategies. These frameworks are commonly utilized to analyze and predict the performance of energy systems over time, facilitating optimization in energy recovery, emissions control, and resource management. These models have been used across different fields in the energy sector, including waste-to-energy (WTE) systems, renewable energy integration, building energy systems, and grid optimization. Looking at the municipal solid waste (MSW) management context, the models can make decisions by stimulating complex processes like combustion, anaerobic digestion and gasification, and energy and material recovery potential.

From a scholarly outlook, Psomopoulos et al. (2009) developed a comprehensive dynamic model for MSW management in Greece. The model quantified energy recovery potential from different waste treatment technologies such as incineration, anaerobic digestion, and recycling. The model provided actionable insights on optimal WTE conversion strategies, thus demonstrating how energy yield varies with waste composition and treatment pathways. Therefore, the work informs us of the value of dynamic models in aligning waste management strategies with energy recovery goals, ultimately reducing landfill dependency and mitigating environmental impacts.

Similarly, Melikoglu (2018) used a dynamic modeling technique to evaluate the energy potential of MSW in Turkey. This study established the substantial role that MSW could play in addressing the nation’s energy needs, underscoring how such models can guide national policy and strategic energy planning. The study modeled variables like waste generation rates and calorific values, giving insight into the feasibility of integrating MSW-based energy into Turkey's renewable energy portfolio.

2.2.7.3 Hybrid Models

The Hybrid model integrates several modeling techniques to leverage their perspective strengths while compensating for individual limitations. These models are especially effective in handling complex systems that are dynamic and nonlinear and have multiple variables interacting. The hybrid models are commonly used in municipal solid waste (MSW) management, energy systems, and environmental modeling. They also facilitate holistic analysis by combining simulation, optimization, machine learning, and statistical techniques.

In the case of the study by Melikoglu (2018), a hybrid model was utilized, and it integrated energy modeling and LCA to assess the energy potential of MSW in Turkey. This approach highlighted the significant role of MSW in addressing national energy needs while incorporating environmental impact. The study underscored energy optimization and policy formulation. In the same context, the study by Nubi et al. (2024) employed a hybrid model that integrated dynamic simulations and life cycle sustainability assessment to evaluate the environmental, economic, and social impacts of WTE systems. This comprehensive approach supported decision-making for sustainable MSW management in resource-constrained regions.

2.3 Empirical Review

African urban areas present a unique opportunity for MSW application in WTE initiatives. Such initiatives lessen the influence of MSW on the environment while providing an added source of energy. The study conducted by Eriisa Yiga Paddy et al. (2024), evaluates the energy potential of incinerating MSW as well as generation of gas from landfills. Generous estimates cited the total energy potential of the 40,593.69 tons waste generated to be approximately 20.5 GWh of energy that has a low heating value of 7.37 MJ/kg, The use of waste to produce energy was evaluated at Mussaka dumpsite, Buea Cameroon. This study by Eriisa Yiga Paddy et al. (2024) did a segregation in the treatment of the waste. Drying was not considered as part of the treatment. Furthermore, Eriisa Yiga Paddy et al. (2024), agrees that the study evaluates the theoretical potential of waste as a fuel. The implementation of such initiatives in practice is quite complex and factors influencing the feasibility of such a WTE system such as steam generation using MSW as a source have not been evaluated. Spatial data can be integrated into the evaluation process to narrow down the list of locations suitable with similar waste composition. In this Study, Nairobi will be evaluated and use of MSW as fuel, drying will also be considered as part of the treatment.

A research by Nyika and Dinka (2022), investigates different methods in which municipal waste can be transformed into energy in the context of African cities. In this evaluation, a maximum per capita production rate of 0.8kg daily, about 125 million tons of waste, is generated. The approaches evaluated were thermal conversion to waste to energy and biochemical conversion of waste to energy rich substrates and gases. Nyika and Dinka (2022), noted that the waste constitution and its subsequent segregation is essential for achieving high energy output. Restraints on financial capacity, human resources and technical constraints were identified as the key causes of the lack of WTE initiatives in Africa. Investment of funds in acquisition of the required equipment, improvement in the human and technological capacity and enactment of stringent measures surrounding renewable energy are some of the solutions proposed. Due to the general nature of this review, it is not possible to ascertain the degree of feasibility that waste to energy initiatives have in different African cities. Prevailing conditions such as the location of the landfill, the specific waste constitution of the demographic producing the waste, and the prevalence of renewable energy alternatives are all factors that have great significance in assessing the feasibility of waste to energy initiatives in African cities.

The study published by Mapereka Francis Chagunda et al. (2023), discusses the potential of utilization of MSW for energy production specifically in low-income economies. The subject country of the study was South Africa. The study area was split into 3 zones, classified according to the economic status of the area and its population density. Waste collected samples were collected from all the zones identified. The waste constitution was calculated from the samples collected. This study found that particular categories of waste have the optimal calorific values and moisture content for WTE. It was also noted that the suitability of a waste class to be used in WTE generation developments is reliant on the amounts generated. The outcome also showed that using paper as a source of fuel in the 240 tonnes/day WTE technology would shelter extra days of operation than plastics and rubber. The total energy output of the MSW was not properly evaluated as the author only provided a prediction of the input related to generation of energy from MSW using waste calorific values to the compositions. Furthermore, the cost of transportation of the MSW to the WTE plant is mentioned but not significantly considered in the waste generation equations provided. Transport is a crucial factor that influences the operational costs and as such will be considered in this study.

Moya et al. (2017) in their paper evaluated the different WTE technologies that exist as thermal incineration, landfill gas utilization, biorefineries and biological treatment of waste. The authors took into account the contextual differences that exist between implementation of WTE in developing and developed countries. These include challenges in collection, transportation in developing countries and abundance of alternatives in developed countries. The need for solid waste management & usage in developing countries is a factor that has been duly considered. Moya et al (2017), asserts that an Integrated Solid Waste Management System (ISWMS) is an ideal solution for developing countries, as it utilizes the municipal solid waste for energy generation while also treating the municipal solid waste. It is an effective and efficient solution. The additional benefit of integrating waste management into waste-to-energy conversion should not be overlooked. The value of waste management might make WTE technologies more feasible for developing countries. However, the study does not provide any cost or financial comparisons that may help justify the use of the ISWMS. Additional factors that may influence the location of an ISWMS in comparison to other thermal WTE conversion plants have not been captured in this study. Such localized factors have been considered in this study.

Amulen et al. (2022) conducted a techno-economic analysis of the energy recovery for WTE plant using MSW. Incineration was chosen as the method of waste-to-energy conversion. The study area selected was Kampala city in Uganda and Kiteezi landfill is the only sanctioned landfill in the city. Waste collection & chemical tests were performed at Kiteezi and the wastes were categorized by specific type. This revealed that the waste had 43% organic matter, 42% mixed fines and 15% recyclable materials. The simulation of the waste incineration plant was modelled using the Aspen Plus and Aspen Hysys V10 systems, where the plant was planned with a volume of 220,000 tonnes of waste/year. The physical tests revealed that the energy/kg of mass at the high heating value (HHV) and low heating value (LHV) were 12.48 MJ/kg and 6.12 MJ/kg respectively. The findings reveal that the simulated plant has a production capacity of 774KWh / ton of MSW. The net present value of such a project would be approximately 34 million USD with an internal rate of return of

12.9% and a ROI of 6 years. With a gate fee of 119USD/tonne, the plant would be able to generate 24 million USD / year. It was observed that most emerging republics produce wet waste with low calorific value and drying the waste would significantly increase their calorific values. It is imperative that all parameters are maximized for efficiency and increased energy recovery as the feasibility of any WTE plant rests on the energy recovered. The process of waste drying treatment will be considered in the value analysis of this study.

Omari et al. (2014) carried out a study to assess the feasibility for municipal solid waste to be used as a potential energy source through waste-to-energy conversion. They considered the following modes of waste-to-energy conversion through; physical (residual derived fuel), thermal (combustion, pyrolysis, gasification and plasma arc-gasification) and biological (fermentation, biogas). Waste was collected in Kaloleni, and Central market located in Arusha. The collected waste was categorized appropriately, and chemical and physical tests were carried out. They revealed that the average expected thermal recovery from dried MSW was 10.6MJ/kg. The study area considered produces 43,772 tonnes of waste per year, therefore the total theoretical energy that could be recovered is 128.9 GWh / year. Omari et al. (2014) did not account for several key parameters essential to assessing the potential of MSW utilization in waste to energy. The higher and lower heating values of MSW are critical in defining the energy recovery limits, yet they were not considered. Additionally, the study overlooked the cost implications of establishing such a plant in Arusha, as well as key feasibility factors, including proximity to the waste source, transportation costs, and the availability of suitable land. A spatial analysis would be necessary to evaluate these aspects, as they significantly impact the viability of WTE development in the region.

Trindade et al. (2018) carried out a study to investigate the maximum amount of useful work that can be generated by a steam cycle of an WTE plant utilizing MSW as a fuel source and conduct an environmental analysis of the system. The goal was to reduce the exergy destruction. Trindade et al. (2018) achieved an 8.4% reduction in exergy destruction by conducting a conventional exergetic analysis on the plant’s main components followed advanced exergetic analysis. This availed more useful energy and reduced the life cycle impact of the MSW incineration plant. The reduction in exergy destruction was represented by an avoidable cost of 2.8 million USD/year whereas the reduced life cycle impact was represented by an emission index reduction of 307 kg CO_{2eq} /MWh and an energy displacement of 3.69kWh/unit of electric energy available. This study is keen to implement learnings from this study regarding the changes made to improve the efficiency of the thermal conversion processes that led to the reduction in exergy destruction.

Hlaba et al. (2016) performed a study to determine if MSW would be viable as an alternative source of energy. The authors also evaluated if the MSW could, through advanced thermochemical techniques, be converted into fuel gases and fluid fuel products. MSW was collected from assorted waste sectors of the businesses and facilities around the Cape Town municipal area. The waste was dried and converted into RDF pellets of varying sizes. The RDF pellets' caloric value was tested with a bomb calorimeter and found to be approximately 19MJ/Kg. This value is significantly high. The thermal stability of MSW was tested using thermogravimetric analysis and the results showed significant mass loss regions at 55 - 265°C, 270 - 410°C and 410 - 502°C. The total sample reduction was 76%. Key areas of improvement for this study include the addition of a waste characterization process, low heating value and high heating values determination for characterized waste.

2.4 Summary of Gaps

From the evaluated studies above, it has been demonstrated that Municipal solid waste is certainly a feasible fuel for the steam generation process. The breakdown of the literature has also presented that there is still scope for enhancement of the assessment of MSW as a fuel source. It has been shown from the studies carried out that various authors did not consider factors such as treatment and transport on the value chain, waste characterization and heating values of the MSW. Entirely, the paper studies evaluated have not given an attempt to combine developments on the waste characterization, consideration of transport from the dumpsite the industry, and treatment of the waste. The studies that have attempted to consider the heating values and maximum exergy from MSW have only used theoretic scenarios.

The following are the study gaps:

- Even though MSW can be used as a substitute fuel for steam generation as studied by Mapereka Francis Chagunda et al (2023), it is evident that heating values, calorific energy outputs and moisture content provide critical insights into energy recovery potential and efficiency for the best treatment method. Transport and treatment cost values are yet to be considered on the overall cost output.

- Although it has been demonstrated by Amulen et al. (2022) that making of pellets in the value chain of MSW utilization increases the overall energy output, there have been no studies that consider other factors such transport and treatment costs, which are critical in determining the overall feasibility and scalability of MSW use in energy recovery.

- Even though it is theoretically evident that proximate and ultimate analysis is considered in analysis of MSW as shown by Hlaba et al. (2016), & Amulen et al. (2022). Studies have not been done on the impact of waste characterization to its implementation of MSW as a fuel. The composition of MSW varies across different locations, directly influencing its calorific value. As a result, dumpsites in different areas contain distinct waste mixes, yet this variation has not been comprehensively assessed in the energy recovery from MSW. Additionally, the choice of which waste characteristics to prioritize optimal energy for fuel applications has not been assessed.

Therefore, this study exploited on some of the gaps of explained here and give improved techniques of assessment of MSW as a fuel to solve steam generation problems in industrial and hospitality sectors.

2.5 Conceptual Framework

This study's conceptual framework was on modeling municipal solid waste (MSW) for steam generation in industrial and hospitality sectors involves several key components and their relationships. The main elements are:

i. Calorific Value Evaluation: This will involve the assessment of the energy potential of MSW and comparing it with biomass, the current fuel source. The calorific values of waste from three different zones in Nairobi was evaluated.

ii. Transport and Treatment Modeling: This component focuses on modeling the impact of transportation distances and pre-treatment methods (drying and segregation) on the overall cost and feasibility of using MSW for steam generation.

The conceptual framework demonstrates how these components interact and build upon each other to comprehensively assess the feasibility and cost-effectiveness of using MSW for steam generation as an alternative to biomass in industrial and hospitality applications in Nairobi.

Figure 2.9 shows the flow and relationships between the key components of the conceptual framework, starting with the calorific value evaluation, progressing through transport and treatment modeling, ultimately leading to a feasibility assessment of using MSW for steam generation in industrial and hospitality sectors in Nairobi. Techno-economic assessment, will be done for a cost valuation of the model

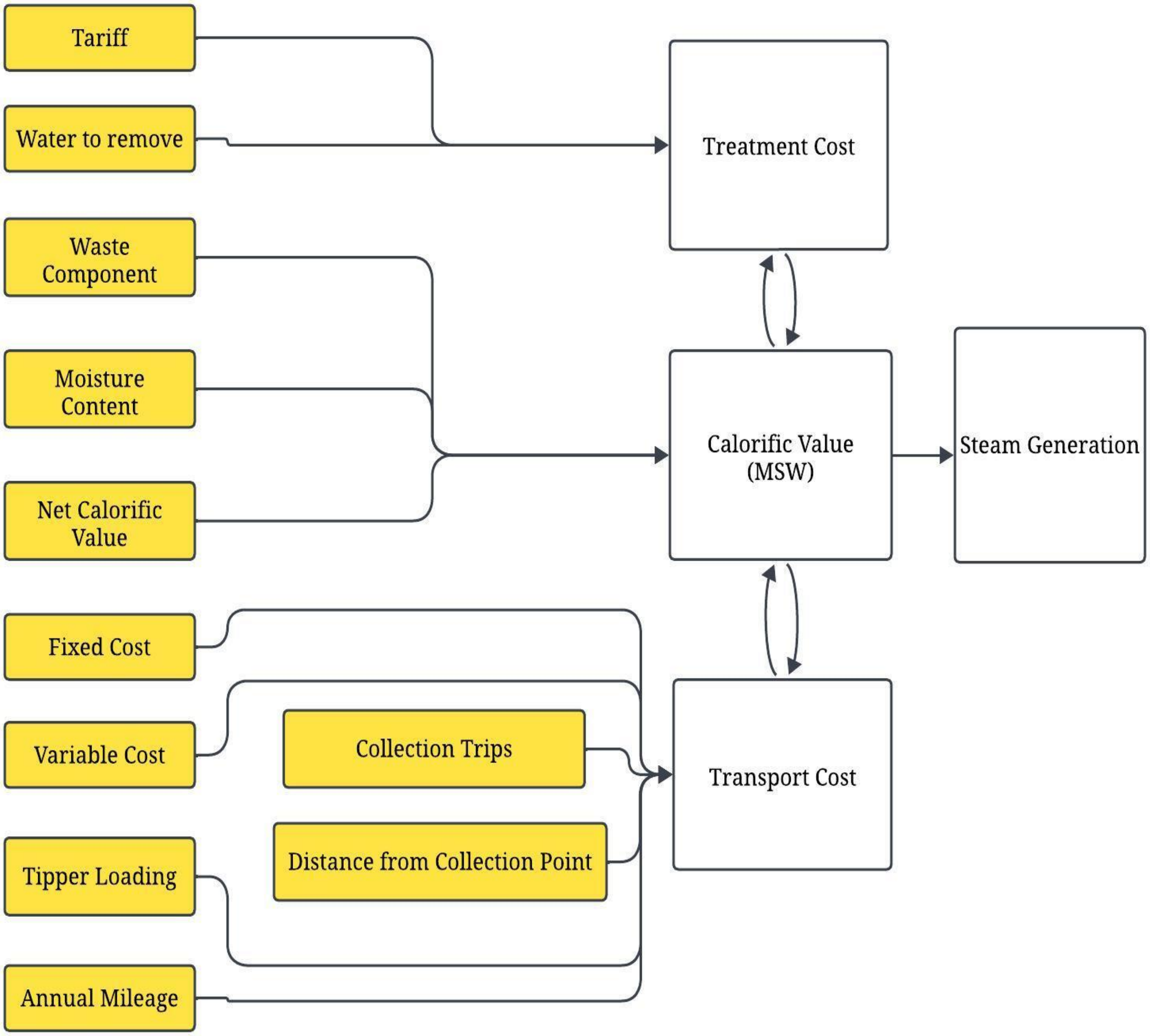


Figure 2.19: Conceptual Framework

CHAPTER 3: MATERIALS AND METHODS

3.1 Introduction

Methods and procedures used to meet the objectives of this study have been explained in this chapter. The foremost part expresses the process of calorific value calculation. MSW and Biomass have been assessed in terms of energy output. The following segment of the chapter explains the modeling methods for transport and waste treatment. This part presents all the governing equations used, the model assumption, and the financial consideration used. The third section discusses techno economical simulations for the steam production calculation.

3.2 Modeling of Municipal Solid Waste Use

The model is a hybrid model formulated as an integrated system that captures the physical and economic processes associated with municipal solid waste utilization for steam generation. It is built upon a series of governing equations for calorific values calculations, transport & drying and levelized cost of steam. The formulation was executed using a VBA Solver platform, to suit the context in relation to the objective of study.

The model first quantifies the energy potential of MSW. The calorific value of the waste is determined by aggregating the individual contributions from its various components. The mass fraction (X_i) of the waste component (*i*th) in the waste mix is multiplied by the specific calorific value (CV_i) of the *i*th component in KJ/kg. The number of waste components (*n*) is accounted for by doing the total sum. in the waste. This is represented in Equation 3.1. Next, the model addresses the cost implications of transporting the waste from collection points to the utilization sites. The transportation cost (T_c) is expressed as the sum of a fixed cost (F_c) and a variable component that is proportional to the monthly mileage (M_m) per truck, scaled by a per-distance variable cost (V_c). This relationship is defined in Equation 3.2.

In parallel, the model incorporates a treatment module focused on the drying process, a crucial step to enhance the waste's low heating value by reducing its moisture content. The energy required for drying is derived from the latent heat of vaporization (L_{hv}) and is a function of the waste mass (M) and its water content (W_c), as expressed in Equation 3.4. To translate this energy requirement into an economic metric, the model further incorporates an electrical tariff (T_t) to estimate the drying cost (D_c) using Equation 3.5. This step ensures that both the physical energy demands, and the corresponding operational costs of the drying process are adequately reflected.

Finally, the technoeconomic performance of the entire waste-to-steam conversion process is evaluated by calculating the levelized cost of steam (LCOS). This metric aggregates the associated costs (A_c), transportation costs (T_c), and treatment - drying costs (K_c) and normalizes the total by the mass of steam produced (P_s). The LCOS is given by Equation 3.7. Here, we account for all additional costs which include capital and operational expenditures, while P_s represents the output of the process in terms of steam mass. The LCOS thus serves as a comprehensive indicator of the economic viability of the integrated waste management and energy recovery system.

3.2.1 Calorific Values Evaluations

This study considered waste collected from three Location in Nairobi.

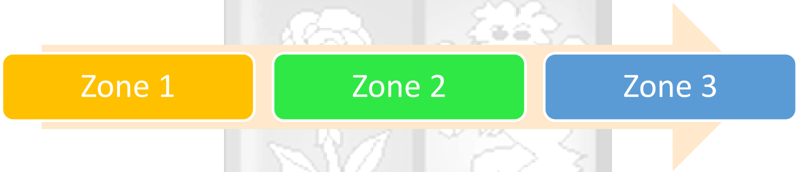


Figure 3.1 Zones in Nairobi

Zones 1, 2, and 3 is categorized as the Nairobi CBD, 15 Km radius of the City Centre, 40 Km radius of the city Centre, respectively. Each zone has a centralized waste collection point, where the waste character is influenced by the commercial and social activities at the zones. Zone 1 is characterized by office and small-scale commercial activities, zone 2 primarily has medium to large scale industrial setups and zone three is populated by domestic setup. Because of the variations of the activities in the different zones, the waste characters will be different.

The different zones affect the waste character and moisture content. This study considered waste as homogeneous throughout the three zones considered.

3.2.1.1 Municipal Solid Waste Energy

Municipal Solid Waste by its nature is a mix of various components in one. In this computation, an approach suggested by Mustia et al. (2021) was used. In the calculation, calorific value for each component was determined as a percentage of the total of the mass, and to get the overall calorific value of the municipal waste. The calorific value considered the waste character and the individual component output. The total calorific value is given as;

$$\boldsymbol{E_c = \sum_{i=1}^{n} X_i \, CV_i} \tag{3.1}$$

Where,

E_c is the total calorific values in KJ/Kg

n is the number of waste components in the waste.

Xi is the mass fraction of the ith component in the waste mix. This gives the portion of the total mass the ith component in the total MSW as a percentage (%).

CVi is the specific calorific value of the ith component in KJ/kg.

3.2.2 Modelling of Value Chains

In this research, two value chains factors were considered. The cost and effect of transport and waste treatment was evaluated. Under this sub-section, the governing equations, for calculation of the transport and treatment was done through the modifications of existing primary equations. The cost calculations influenced the final total cost for levelized cost of steam calculation. In waste treatment, drying was only considered.

3.2.2.1 Transport

Transport under this study was the total distance between the waste collection points; Dandora and Kangemi, to the waste utilization point; Company A and Company B. Neto (2020), in his study on total logistical costs, considered both fixed and variable costs influencing waste transportation. This study adopted Neto’s transport equation, assuming the routes to the two companies were linear. The factors under this model calculation considered, are the transport distance from the two collection points in Nairobi, to point of use, the cost of buying waste and variable costs as maintenance and fuel.

The total transport cost is given in equation 3.2 as:

$$T_c = (F_c \times C_t) + (V_c \times M_m) \qquad 3.2$$

Where,

T_c is the total cost of transportation in Ksh

F_c is the fixed cost in Ksh. In this model it will be the cost of buying waste per truck

V_c is the variable cost that encompasses the fuel, maintenance, and salaries costs. It is given as Ksh/Km

C_t is the number of collection trips

M_m is the Annual milage per truck per route in Km

Collection trips is given as:

$$C_t = \frac{W_c}{T_p} \qquad 3.3$$

Where,

C_t is the number of collection trips

W_c is the waste to be collected in Kg

T_p is the Tipper truck loading size in tons

Annual Milage is given as:

$$M_m = C_t \times (C_d \times 2) \qquad 3.4$$

Where,

C_t is the number of collection trips

C_d is the distance from collection point to point of use in Km

3.2.3 Waste Treatment

Drying was only considered under treatment. The drying treatment was used to remove the water content from the solid waste to enhance the low heating value. This is an internal process that the facilities conduct once they receive the waste, hence the cost for storage will not be considered. Firewood, as currently used, is internally stored at the facilities. As suggested in the study by ThiKimOanh et al. (2015), latent heat of vaporization is considered in the removal of water content, to get the total energy needed to dry waste. The total cost of treatment is determined based on equation 3.5 as;

$$K_c = D_c \qquad 3.5$$

Where,

K_c is the total cost of treatment in Ksh

D_c is the drying cost in Ksh

3.2.3.1 Drying

As suggested in the study by ThiKimOanh et al. (2015), latent heat of vaporization was considered in the removal of water content, to get the total energy needed to dry waste as shown in equation 3.6.

$$E_r = W_c \times M \times L_{hv} \qquad 3.6$$

Where,

E_r is the total drying energy in KJ

W_c is the total water content in %

M is mass in Kg

L_{hv} is latent heat of vaporization in KJ/Kg

In this study, tariff is added to get the cost of the energy used for drying. The assumption considered was that electrical drying method was used. The equation therefore gives the energy and cost output under drying as shown in equation 3.7:

$$D_c = \frac{E_r}{(3.6 \times 10^6)} \times T_t \qquad 3.7$$

Where,

D_c is the total cost of drying in Ksh

E_r is the total drying energy in KJ

T_t is the electricity tariff in Ksh

3.2.4 Techno-economic Analysis

This study calculated the levelized cost of steam (LCOE) as the totals of the associated costs, transport costs and the treatment costs. This calculation was done with the existing equations as suggested by Eltamaly and Mohamed (2018).

$$LCOE(Ksh/KWh) = \frac{CWECS}{Epy} \qquad 3.8$$

Where,

LCOE is the average cost per unit of electricity generated over a system's lifetime

WECS (CWECS) is total annualized cost

Epy is annual electricity produced by the system

3.2.4.1 Levelized Cost of Steam

In this study, steam is considered the primary output, serving as the key parameter for analysis.Substituting with the equation 3.8 above, the levelized cost of steam was considered, using the associated costs, cost of transport, cost of treatment against the total tonnage of steam produced, in the same period.

The levelized cost of steam was calculated by the governing equation in equation 3.9:

$$LCOS = \frac{A_c + T_c + K_c}{P_s} \qquad 3.9$$

Where,

LCOS is the levelized cost of steam

A_c is associated costs in Ksh, which is CAPEX for equipment and infrastructure and OPEX for fuel, maintenance, labor, and other recurring expenses

T_c is transport cost in Ksh

K_c is the treatment cost in Ksh

P_s is produced steam in Kg

3.3 Study Area

The study was conducted in Nairobi County, which is situated in Capital -central area of Nairobi.

According to the latest population data, Nairobi County had a total population of 4,397,073 with 1,506,888 households spread within an area of 696.1 square kilometers (km²), translating to 2.9 persons per square kilometer population density (KNBS, 2019).

Company A is a sweet producing company located in Mombasa Road, in the inland development area. Company B is a luxury hotel, located in the Nairobi Westlands area. They both use steam for their heat process: laundry, chemical mixing and sanitation cleaning. Company A was considered as it fits the industrial setup and Company B fits the hospitality setup.

3.4 Data Collection

Secondary data was used in this study. The data was gathered from Nairobi City County (NCC), National Environment Management Authority (NEMA), and the Kenya National Bureau of Statistics (KNBS). The data collected included waste characterization data from NEMA, information on waste collection points, dumpsites, and the quantity of waste collected per day and month from NCC, as well as operational expenditure (OPEX) costs for waste collection trucks per sector and other related financial data from KNBS. As Jena and Kar (2019) points out, cleaning of secondary data involves identification of errors, inconsistencies and missing values. This research used R programing for the data cleaning to maintain transparency and reproducibility of the research findings. R programing was also used to check on completeness and accuracy for any outliers in the data sets.

3.5 Data Presentation and Scenarios Approach

In this study, the developed model integrated the governing equations for waste treatment-drying, transportation, calorific value assessment, and levelized cost of steam (LCOS) analysis, based on data considered and used. Computational analyses were performed using the Visual Basic for Applications (VBA) Solver. Distinct cost-modification scenarios were done, where scenario one entailed a 15% adjustment to waste fixed costs while scenario two involved a 30% modification. Table 3.1 provides a summary of the approaches employed.

Table 3.1 Scenario approaches summary

Scenario	Approach	Comment
One	Waste fixed cost change by 15%	Effect on the LCOS
Two	Waste fixed cost change by 30%	Effect on the LCOS

Fixed cost adjustments of 15% and 30% were implemented in this analysis to perform a sensitivity study that captures the inherent uncertainties in capital expenditure estimates for waste management systems. The 15% variation reflects moderate fluctuations typical of stable market conditions, while the 30% adjustment accounts for more volatile scenarios driven by regulatory changes, material price variability and unforeseen operational challenges. This approach is consistent with standard practices in energy and waste management analyses, and recent studies underscore the importance of evaluating financial performance across a range of fixed cost uncertainties (Lazard, 2021; International Energy Agency, 2020).

3.6 Ethics in Research

This study was firmly committed to upholding the highest ethical standards as outlined by the Strathmore University research guidelines. To ensure ethical conduct, all necessary documentation was submitted to the Strathmore University Institutional Scientific and Ethics Review Committee (SU-IERC) for comprehensive review.

The research was conducted in accordance with the ethical research provisions of the University. Full disclosure on the uses of the data was provided to enhance the ethicality of the process. Respondents were informed that the data was intended for research purposes and would be shared with examiners, classmates, and during seminars.

By adhering to these established ethical frameworks, the research aimed to contribute to a robust and responsible knowledge base within the field.

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter presents performance results for municipal solid waste use in steam generation. The chapter is ordered into three sections. The first section presents the results of calorific values of Biomass and Municipal Solid Waste. The second section presents the transport and treatment model results, and the final section covers the techno-economic simulation of Municipal solid waste as feedstock.

4.1 Data collected

Secondary data was collected from both Company A and B. This was biomass (firewood) in Kg, water usage (litres) for the boilers, moisture content (%) from the biomass bought and the electrical tariff (Ksh/KWh) from their electrical bill. In addition, cost data from Dandora and Kangemi waste collection points, specifically, the cost per truck-fixed cost and the variable cost (Ksh/Km) were gathered. This data was obtained from a third-party company specializing in recycling and waste management services. The biomass data is recorded daily, when used directly in the boiler, while the moisture content is measured when the biomass is brought into the facility, by the quality department. The total wood cost and water cost was obtained from the engineering delivery notes.

The collected data is summarized in table 4.1 and 4.2 below:

Table 4.1: Summary data from Companies A & B

	Company A	Company B
Biomass (Kg)	4,563,990.00	2,045,745.60
Wood Cost (Ksh/Kg)	5.80	7.00
Moisture Content (%)	23	27
Annual Water consumption (Ksh/Litre)	16,880,856.00	1,017,933.00
Waster Cost (Ksh/Litre)	0.005	0.055
Tariff (Ksh/KWh)	27	24

Table 4.2: Summary of data collected for Dandora & Kangemi

	Dandora	Kangemi
Fixed cost (Ksh)	48,300	48,300
Variable cost (Ksh/Km)	120	120

4.2 Calorific Values Analysis

Two companies, A and B, were used to collect data for analysis. Company A is located at zone 2, While company B is in zone 1, as shown in figure 3.1. Company A is an industrial setup, where the core business is production of sweet products, for local and export consumption. Company B is a hotel where they offer both hospitality and conference services in Nairobi. Waste data was collected in the Nairobi area and was assumed to be homogenous in categorization from the three zones.

4.2.1 Biomass Calorific Values

Both company A and B use a mix of various biomass types. The preferred type is off-cut pieces and logs of Eucalyptus globulus. The biomass logs and offcuts are delivered through third-party vendors, where they are weighed and their moisture content measured. The minimum acceptable moisture content at company A is 29%, as per their measurement standards. Company B does not take the moisture value into consideration. These figures fall below the Kenya Bureau of Standards (2021), standards on solid fuels where they recommend moisture content in biomass fuels should below 20% for efficient combustion.

Table 4.3: Biomass Calorific Values

	Firewood used -yearly (Kg)	**Average moisture content (%)**
Company A	4,563,990.00	23
Company B	2,045,745.60	27

Company A uses a annual consumption of 4,563,990.00 Kg of firewood at an average of 23% moisture content, with a 5-ton water tube boiler. Company B uses 2,045,745.60 Kg of firewood, with an average of 27% moisture content, with a 2-ton water tube boiler in use. The biomass considered is Eucalyptus globulus, which accounts for 90% of the biomass quantities used. This research assumes the biomass use is homogeneous, with the recorded average moisture content.

The gross calorific values and the net calorific values were calculated according to the principle research of J Peredo, et al. (2006). The Net Calorific Value (NCV) is accounted by removing the energy needed to vaporize water in the firewood, as shown in equation 4.1.

$$NCV = GCV - 2.44 \times (moisture\ fraction) \qquad \textbf{\textit{4.1}}$$

The latent heat of vaporization of water is removed by subtracting 2.44 MJ/kg per unit against the moisture content. 23% and 27% moisture content are removed from Company A and Company B respectively. This gives the energy required to vaporize water during combustion. Figure 4.1 shows a comparison of company A and Company B heating values.

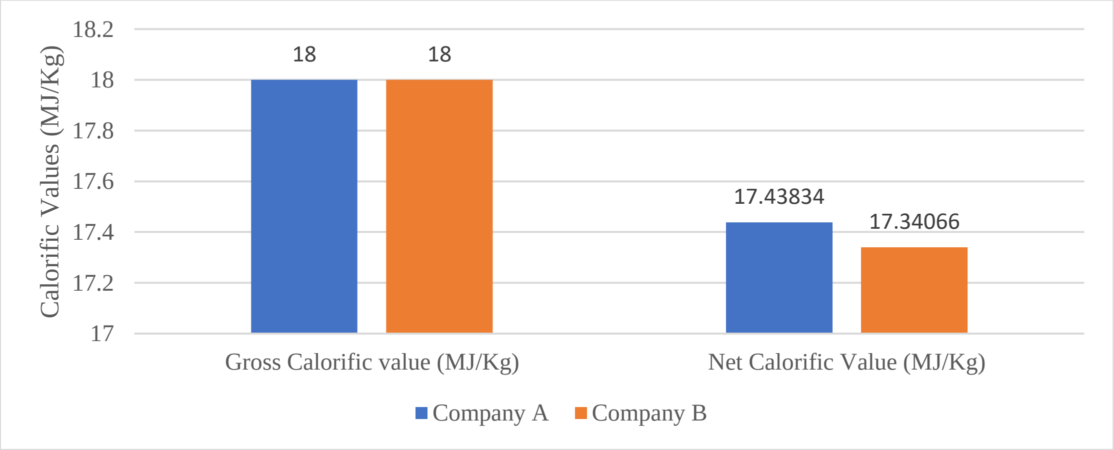


Figure 4.1 Comparison of heating values

As demonstrated in Table 4.3, both company A and B use the same type of biomass energy. The moisture content is 23% and 27% for Company A and B respectively. Figure 4.1 above shows that the gross calorific values are equal at 18 MJ/Kg, while the net calorific value has a difference of 0.59% with Company A at 17.43834 MJ/Kg and Company B at 17.34066 MJ/Kg. The observed differences in Company A & B tallies with literature in J Peredo, et al. (2006), which indicates that the net calorific value is impacted by the moisture content, while the heat of vaporization of water remains constant.

4.2.2 Municipal Waste Calorific Value

In this study, a consistent approach was adopted by treating the waste characterization as homogeneous across the three zones, in Nairobi. The waste characterization data were obtained from the preparatory survey for integrated solid waste management in Nairobi City conducted by the Japan International Cooperation Agency (2010), as presented in Table 4.4 below:

Table 4.4: Waste Composition and Average Percentages

Waste Composition		**Average Percentage %**
Food Waste		65.41
Paper	Recyclable Paper	4.80
	Recyclable Cardboard	1.27
	Mixed Paper	0.89
	Diapers	2.57
	Subtotal - Paper	9.53
Plastics	Plastic Sheet	3.09
	Recyclable Plastics	3.10
	PET Bottles	1.95
	Other Plastics	0.57
	Subtotal - Plastics	8.71
Rubber & Leather		0.24
Textiles		0.92
Yard Waste		2.46
Lumber & Logs		0.31
Other Org. Waste		2.17
Organic Waste - Subtotal		89.74
Glass	Returnable Bottles	0.97
	Other Live Bottles	0.42
	Glass bins	0.03
	Broken Glass	1.19
	Glass-Subtotal	2.61
Metals	Tin Cans (steel cans)	0.83
	Aluminum cans	0.68
	Copper	0.00
	Other Metals	0.39
	Metal-subtotal	1.90
Dirt, Ash, Stone, Sand		5.27
Inorganic Waste - Subtotal		9.78
	Unclassified Residual Waste	0.38
	Domestic Hazardous Waste	0.04

	Batteries - Dry Cells	0.05
	Other Domestic Hazardous Wastes	0.05
Total		100.04

Table 4.4 above shows the waste distribution of waste in Nairobi. Organic waste accounts for 89%, where 65.4% of this organic waste is from food waste. This is attributed to urban activities, particularly market operations and the generation of food waste from residential and commercial sectors. Glass, Metals and other inorganics account for less than 11% as most of the substances are used back for recycling purposes or reused for other activities.

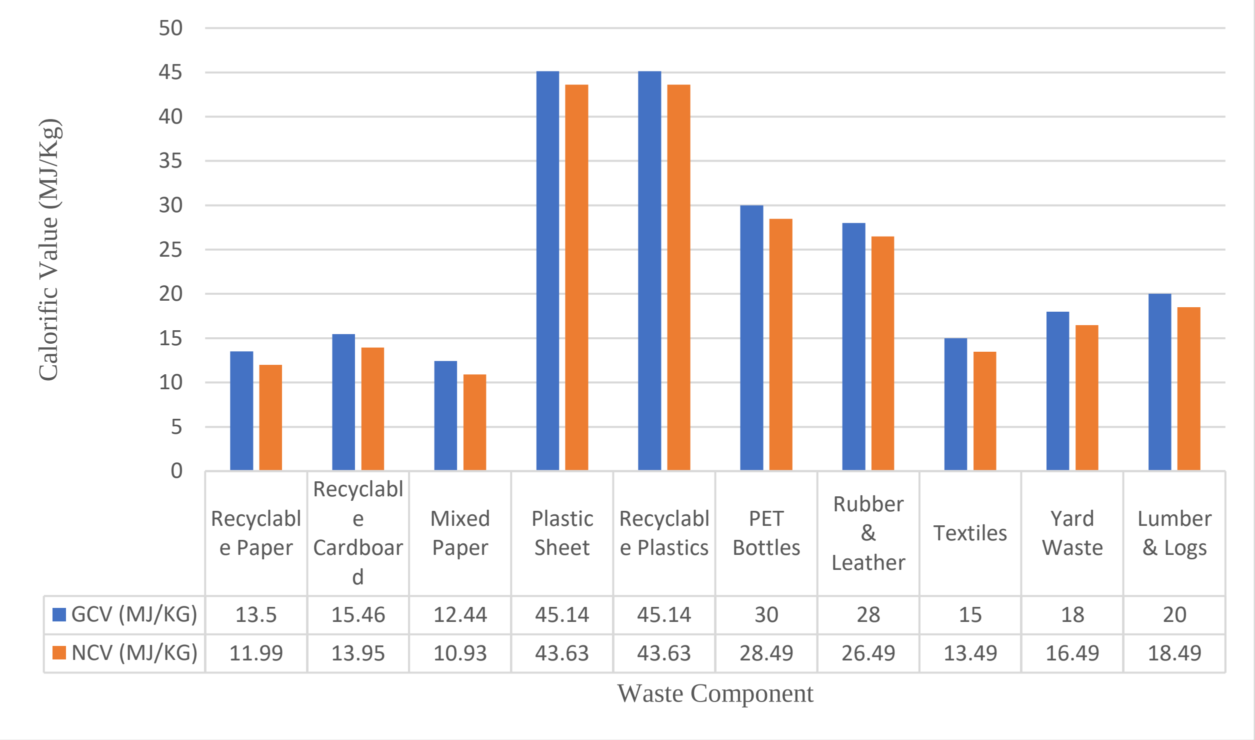
The waste characterization dataset in table 4.4 was used to estimate the moisture content of the components under consideration as Fuel. The overall moisture content of the municipal waste stream was measured at approximately 62.04% (JICA, 2010). Recyclable paper, recyclable cardboard, mixed paper, plastic sheet, recyclable plastics, PET bottles, rubber & leather, textiles, yard waste, and lumber & logs were considered as the waste character for the MSW feedstock, as shown in table 4.5.

Table 4.5: Waste Component water composition in Grams and %

Waste Composition	**Moisture (Grams)**	**Component (%)**
Recyclable Paper	29.77	4.80
Recyclable Cardboard	7.88	1.27
Mixed Paper	5.54	0.89
Plastic Sheet	19.18	3.09
Recyclable Plastics	19.20	3.10
PET Bottles	12.11	1.95
Rubber & Leather	1.46	0.24
Textiles	5.74	0.92
Yard Waste	15.23	2.46
Lumber & Logs	1.95	0.31
Total	**118.06**	**19.03**

Each selected component’s proportional contribution in grams was derived by multiplying its percentage composition within the total waste by the overall mass of one Kg. The mass of water attributed to each fraction was allocated based on its share of the total sample, of 620.4 grams-based on the initial 62.04% of moisture content. Converting these moisture values back into percentages provided the total moisture content of the fuel.

The gross calorific values and net calorific values of each selected waste component are presented in Figure 4.2, highlighting their potential as fuel sources.



	Recyclable Paper	Recyclable Cardboard	Mixed Paper	Plastic Sheet	Recyclable Plastics	PET Bottles	Rubber & Leather	Textiles	Yard Waste	Lumber & Logs
🟦 GCV (MJ/KG)	13.5	15.46	12.44	45.14	45.14	30	28	15	18	20
🟧 NCV (MJ/KG)	11.99	13.95	10.93	43.63	43.63	28.49	26.49	13.49	16.49	18.49

Figure 4.2: Municipal Solid Waste Components Calorific Values

The gross calorific values was determined based on findings from the research done by Igniss Energy (2025), Atul & Samadder (2017), Manoj, Nandeshwar &Bharat (2020), and Roger (2013) that gives the heating values for various waste materials. These values were then mapped onto the waste components identified, ensuring each component's GCV aligns with empirical data on its typical heating performance. The NCV were then calculated using equation 4.1.

Plastics have the highest net calorific values at average at 45MJ/Kg, whereas paper, yard waste, and lumber display moderate values averaging 14MJ/Kg. The orange bars graphs represent the NCV, which is lower because of moisture content. The total net calorific value of the waste considered is 23.80 MJ/Kg.

The higher calorific value of MSW compared to biomass makes it a more energy-dense alternative, Figure 4.3 illustrates this comparison,

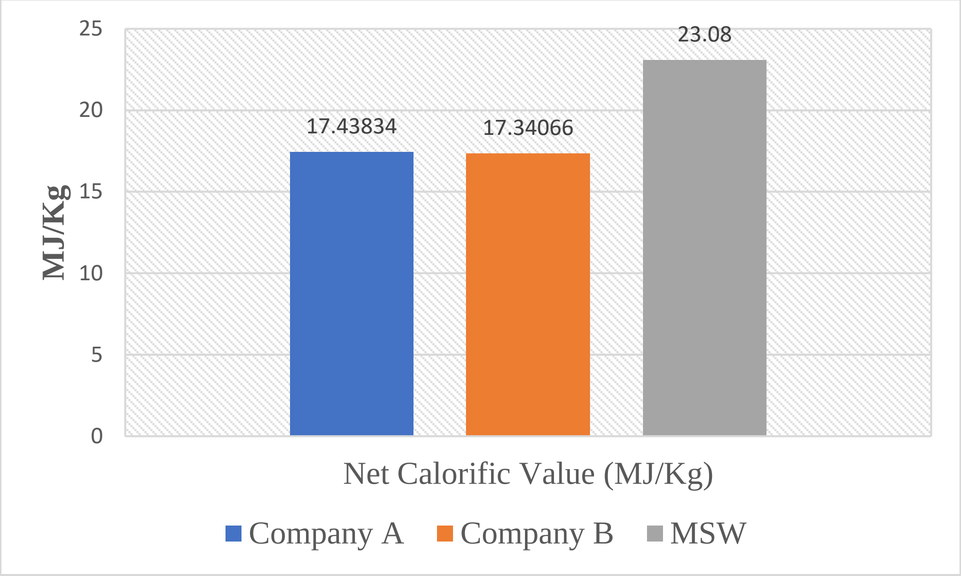


Figure 4.3: Comparison of MSW and Biomass Calorific Values

Figure 4.3 above shows MSW has a 37 percent higher energy per Kg than biomass used in companies A and B.

4.3 Transport and Treatment Model in Municipal Solid Waste

This section is presented in two parts. The first part deals with the analysis of distance and cost in the transport model. The linear distances to the companies were determined, as well as the annual energy requirements. The second part presents the cost for treatment of the waste. This study was limited to two collection points, Dandora and Kangemi points. This model used was statistical and dynamic.

4.3.1 Transport

The proposed model was validated and the output tested. Statistical analysis was done using the governing equations, that is equation 3.2. This section presents the results of the cost, distance, trips from Company A &B and the collection points.

Firewood data from company A and B was used as the baseline data to determine the annual energy consumption for steam generation as shown in figure 4.4.

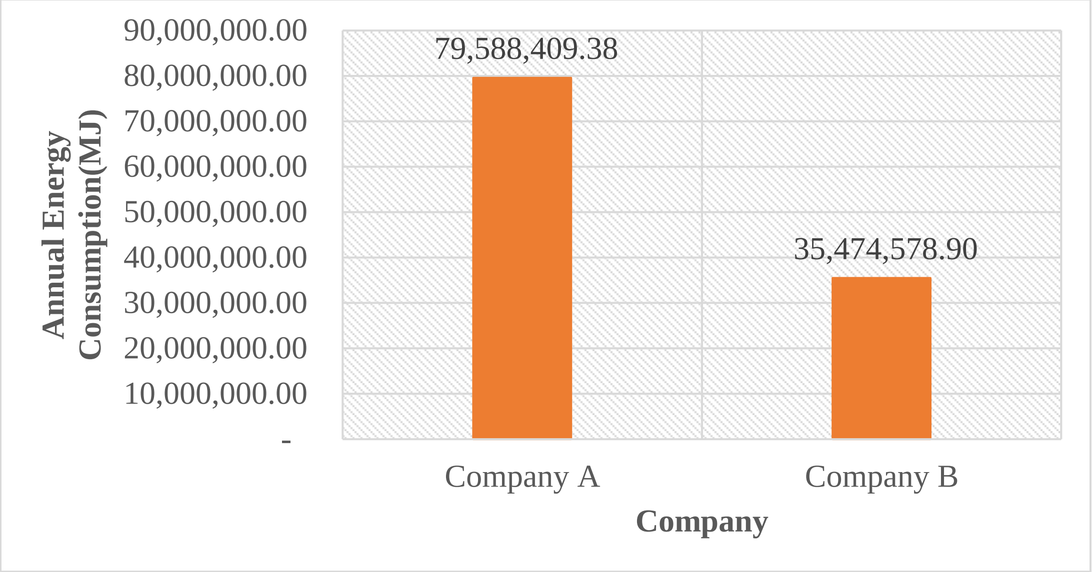


Figure 4.4: Annual Energy Consumption (MJ)

Figure 4.4 illustrates a comparative analysis of the annual energy consumption of Company A and Company B. The energy calculations were obtained by multiplying the annual biomass consumption in kg by the respective calorific values, both in company A and B as shown in equation 4.2

$$Total\ Energy\ (MJ) = Annual\ consumption\ (Kg) \times\ Net\ Calorific\ value(MJ/Kg) \qquad \textbf{4.2}$$

The annual energy consumption and net calorific value is highlighted in table 4.1 and figure 4.1 respectively.

There is 44,113,830.48 MJ difference in energy usage between the two companies, where Company A consumes 79,588,409.38 MJ of energy while Company B consumes 35,474,578.90 MJ of energy. The difference in variations is due to the operational scale, the nature of steam-intensive processes implemented in the two companies. Company A operates at a higher energy intensity than Company B, because its primary operations are industrial in nature.

The energy used in company A and B were determined to get the total Municipal solid waste demands by dividing the total energy use against the MSW calorific value as shown in equation 4.3

$$MSW\ Demand\ (Kg) = \frac{Total\ Energy\ use\ (MJ)}{MSW\ Calorific\ value\ (MJ/Kg} \qquad \textbf{4.3}$$

Figure 4.2 highlights the calorific values Municipal solid waste averaged at 23.80 MJ/Kg. This data was used to calculate the Municipal solid waste demands in Kg as shown in equation 4.3 to determine the annual energy as shown in Table 4.6;

Table 4.6: Firewood and MSW demands in Kgs

	Company A	Company B
Annual Energy Consumption MJ)	79,588,409.38	35,474,578.90
Annual Firewood use (Kg)	4,563,990.00	2,045,745.60
MSW Demand (Kg)	3,343,531.71	1,490,297.15

A total of 4,563,990 Kg and 2,045,745.60 Kg are used in company A and B respectively. This is used to sustain the energy need as shown in Figure 4.4. The waste demand to generate the same amount of energy will be 3,343,531.71 Kg and 1,490,297.15 Kg for company A and B respectively. This reflects a 27% reduction in the amount of Kg of the energy source to meet the same energy requirement.

4.3.1.1 Distances and Costing

This study considered two waste collection points: Kangemi and Dandora waste collection points. Kangemi is controlled by a private developer while Dandora is controlled by the Nairobi City County government. Distances to company A and B was obtained from Google maps (2025) and presented in table 4.7 below. The distances were assumed to be linear.

Table 4.7: Distances form collection Points to Company A and B

	Kangemi Point	Dandora Point
Company A	24.40	15.20
Company B	12.30	14.90

The distance was used in the model, as highlighted in equation 3.2, to compute the total costings as presented in tables 4.8 and 4.9 below:

Table 4.8: Kangemi point- Transport costs

Kangemi Point	**Company A**	**Company B**
Annual Demand (Kg)	3,343,531.71	1,490,297.15
Tipper loading size (20 tons trucks)	20	20
Distance from Collection Point (Km)	24.4	12.3
Fixed Cost (Ksh)	48,300	48,300
Variable Cost (Ksh/Km)	120	120
Annual Mileage (Km)	8,158.22	1,833.07
Collection trips	167.18	74.51
Total Cost (Ksh)	**9,053,615**	**3,819,035**

Table 4.8 above provides a comparative overview of waste collection logistics at Kangemi Point, contrasting Company A and Company B in terms of annual demand, trip frequency annually, and fixed and variable costs. Both companies employ a 20-ton tipper to maximize carrying capacity per trip. Consequently, the total number of collection trips is determined by dividing the annual demand, as determined in table 4.6, by the tipper's 20-ton capacity. This approach ensures that the vehicle's capacity is fully utilized in each run, thereby minimizing underutilization (Natalie & Geert , 2019).

Company A has a higher annual demand of MSW at 3,343,531.71 kg and a longer distance from the collection point at 24.4 km, resulting in 92.67 more trips and an elevated annual mileage at 8,158.22 km, as calculated using equations 3.2 and 3.4. These factors collectively increase the total cost to Ksh 9,053,615. By comparison, Company B's reduced demand of MSW is 1,490,297.15 kg and shorter distance of 12.3 km yield fewer trips at 74.5 and significantly lower annual mileage at 1,833.07 km. This results in the total cost at Ksh 3,819,035.

Company A's higher demand directly correlates with increased operational hours at the facility, and the current firewood consumption. The fixed cost for buying waste per truck is Ksh 48,300 for both companies, which is an expense that remains constant regardless of distance or trip count. In contrast, the variable cost is Ksh 120 per kilometer encompasses, the costs for operational outlays such as vehicle maintenance, fuel, and driver wages.

The total annual mileage calculation as shown in equation 3.4 highlights how distance exerts an effect on overall operating costs. Florence & Sabine (2023), emphasize, that the interplay between distance and trip frequency is a key determinant of cost efficiency, in waste management. This cost asymmetry highlights economies of scale in transportation. Company B achieves a lower cost per kilogram transported of Ksh 2.56/kg compared to Company A with Ksh 2.71/kg, despite identical capacities in cost of buying MSW and variable cost per truck, hence showing distance and demand volume are critical levers for cost containment

Table 4.9: Kangemi point- Transport costs

Dandora Point	**Company A**	**Company B**
Annual Demand (Kg)	3,343,531.71	1,490,297.15
Tipper loading size (20 tons)	20	20
Distance from Collection Point (Km)	15.2	14.9
Fixed Cost (Ksh)	48,300	48,300
Variable Cost (Ksh/Km)	120	120
Annual Mileage (Km)	5,082.17	2,220.54
Collection trips	167.18	74.51
Total Cost (Ksh)	**8,684,489.26**	**3,865,532.74**

Similar analysis was done for Kangemi collection point as done for Dandora. Table 4.9 shows the operational dynamics of waste transportation from Dandora Point, where Company A and Company B have nearly the same distances from Dandora at 15.2 km vis-a-vis 14.9 km yet exhibit a 2.25-fold disparity in total costs. This percentage change shows how waste demand volume and waste trip collection frequency dominate the distance proximity of the dumpsite as cost drivers.

Despite marginal differences in distance, Company A's higher annual demand of 3,343,531.71 kg necessitates 167.18 trips, which is over double Company B's 74.5 trips. This translates to 5,082.17 km of annual mileage compared to Company B's 2,220.54 km. This shows a non-linear escalation of costs where Company A's variable expenses is Ksh 609,860 while Company B's is Ksh 266,465 due to the compounding effect of trip frequency on mileage, even as fixed cost and the variable cost remain the same. This scenario underscores the importance of monitoring both demand patterns and routing strategies in transporting waste. Figure 4.5 below provides a visual comparison of these differences.

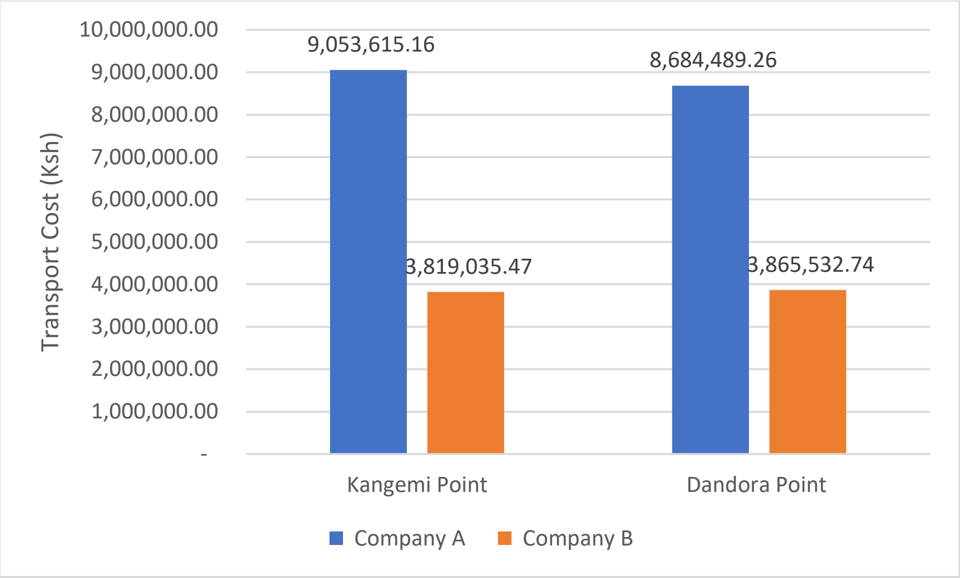


Figure 4.5: Comparison of cost from Dandora & Kangemi for companies A & B

4.3.2 Treatment Drying

Controlling moisture content is critical to optimizing waste quality and performance in combustion. This research targeted a final moisture content of 15%, a level extensively researched by Tesfaldet, Oyedun & Hui (2013), where they point out that combustion will occur optimally by reducing excess energy waste and ash content build up.

The input parameters used in the calculation for the drying cost are shown in table 4.10.

Table 4.10: Input parameters for drying model

Input Parameters	
Initial Moisture content (%)	19.03%
Final Moisture content (%)	15.00%
Ambient Temp (degrees)	25
Latent Heat of vaporization (KJ/Kg)	2260
Specific Heat capacity of water (J/g·°C)	4.18

The approach involved calculating both sensible heat; the heat to raise water temperature from ambient 25°C to 100°C, and latent heat; the heat to convert liquid water into vapor. Using both the specific heat capacity of water at 4.18 kJ/kg·°C and its latent heat of vaporization at 2260 kJ/kg allowed for the determination of total energy in kilojoules, which was converted to kilowatt-hours, as down in table 4.11 below.

Table 4.11: Total cost of drying

	Company A	Company B
Total waste demand (Kg)	3,343,531.71	1,490,297.15
Total amount of water to be removed (Kg)	134,744.33	60,058.97
Sensible heat (KJ)	42,242,346.78	18,828,488.66
Latent Heat (KJ)	304,522,180.92	135,733,283.49
Total Energy	346,764,527.70	154,561,772.15
Tariff (Ksh/KWh)	27	24
KWh Used	96,323.48	42,933.83
Total Cost (Ksh)	**2,600,733.96**	**1,030,411.81**

The results, derived from Equation 3.7, where resulting kilowatt-hour values are multiplied by each company's respective tariff rates to quantify the drying cost, offering a clear financial indicator of yearly consumption. In comparative analysis, Company A's higher total waste mass demand necessitates a substantially higher energy input and, consequently, a higher overall cost, whereas Company B demonstrates a reduced cost profile due to smaller total mass demand. These findings emphasize how it is essential to control moisture content. The marginal reduction of the moisture content from 19.04% to 15%, in the moisture translated to a total drying cost of 3.6 million Ksh across the two companies.

It is noted that the drying value chain adds to the operational expenditure of both companies, while it ensures the combustion efficiency is optimized by maintaining a moisture content of 15%

4.4 Techno-Economic Analysis

This study, sought to do a techno-economic analysis, of MSW and biomass waste as feedstock for steam generation, with the analysis anchored in equation 3.9. This research established a comparative baseline by calculating the costs associated with use of biomass against the use of MSW. This incorporated the costs details of drying, transportation, OPEX, and CAPEX.

A summary table of the costs considered is presented in table 4.12 below,

Table 4.12: Costs associated in Company A & B

		Company A	**Company B**
CAPEX	Boiler (Ksh)	32,000,000.00	25,800,000.00
OPEX	water cost (Ksh/Litre)	0.005	0.055
	Annual water used (Litres)	16,880,856.00	1,017,933.00
	Annual water cost (Ksh)	**84,404.28**	**55,986.32**
	Maintenance (Monthly)	54,734.22	20,000.00
	Annual maintenance (Ksh)	**656,810.64**	**240,000.00**
	Wood Cost (Kg/Ksh)	5.8	7.0
	Annual Wood Used (Kg)	4,563,990.00	2,045,745.60
	Annual wood cost (Ksh)	26,471,142.00	14,320,219.20
STEAM	**Annual Steam Production (Kg)**	**29,821,237.38**	**13,343,581.61**

Table 4.12 above shows the yearly CAPEX, OPEX and steam figures. Company A's boiler CAPEX is Ksh 32,000,000 compared to Company B's Ksh 25,800,000 (Lean Energy, 2025), reflecting a higher initial investment because company A us a 5-ton boiler while Company B uses a 2-ton boiler. These capital expenditure figures are derived from supplier and installer quotations, ensuring accuracy based on real market pricing.

Operational expenses are further disaggregated into the feedwater used, maintenance cost and wood cost. Company A benefits from a lower water cost at Ksh 0.005 per litre but consumes significantly more water; 16,880,856 litres annually than Company B where 1,017,933 litres of water is consumed at Ksh 0.055 per litre resulting in moderate water costs of Ksh 84,404 versus Ksh 55,986 per annum, respectively. Maintenance expenditure also differs, with Company A incurring a monthly cost of Ksh 54,734; annualized to Ksh 656,810 compared to Company B's Ksh 20,000 monthly resulting in Ksh 240,000 annually. Both Companies have their own borehole water consumption, but Company B outsources their maintenance services. The maintenance costs presented in this analysis were obtained directly from each company's operational records. Company A's higher maintenance cost is associated by the continuous, high-volume operations at the facility necessitate more frequent servicing.

To illustrate the impact of wood usage on operational costs and steam output, a comparative analysis of Company A and Company B is presented in figure 4.7

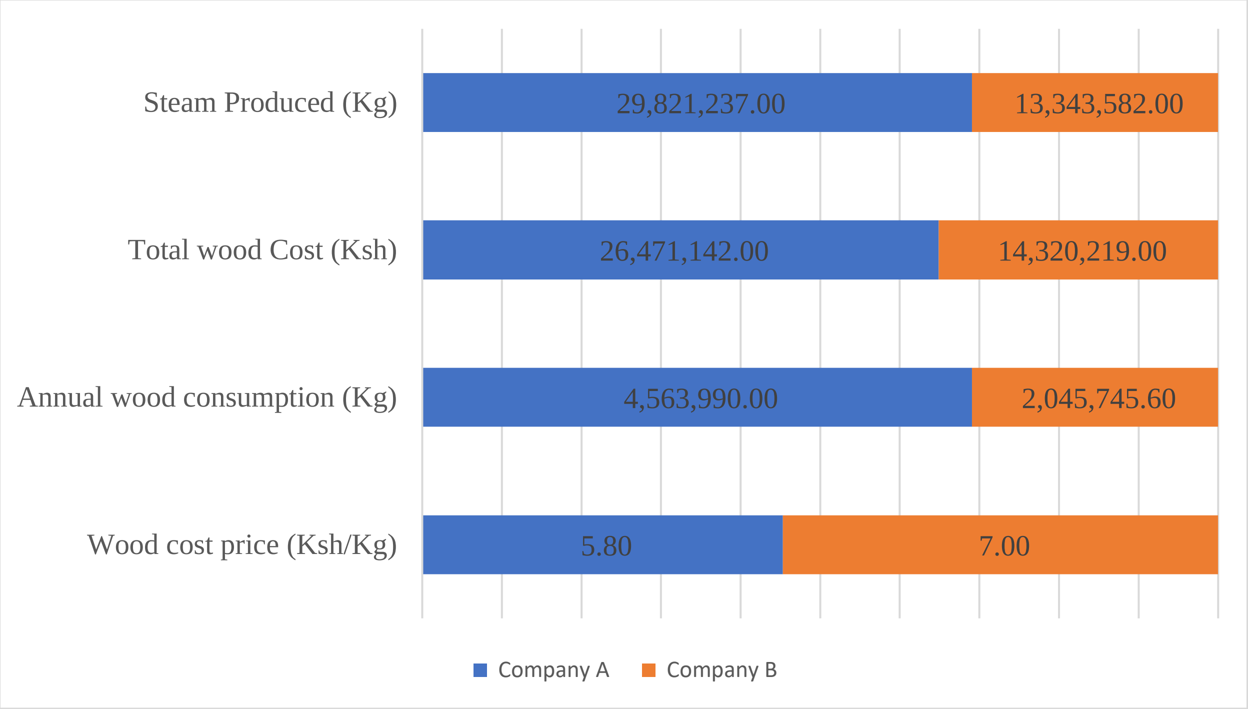


Figure 4.7: Comparison of total wood cost & Steam for companies A & B

The costs are quantified by multiplying the wood usage against the wood cost per Kg. As indicated in table 4.1, Company A's unit cost of Ksh 5.8 per kg and its annual consumption of 4,563,990 kg lead to an annual wood cost of Ksh 26,471,142, whereas Company B's unit cost at Ksh 7.0 per kg is higher and lower usage of 2,045,745.60 kg results in Ksh 14,320,219 annually. These input cost differentials correlate with the resultant steam output, with Company A generating approximately 29,821,237 kg of steam per year versus 13,343,582 kg for Company B.

Further evaluation of the model incorporated the discounted costs of firewood and MSW sourced from Dandora and Kangemi, factoring in the applicable discount rate and the boiler's operational time as shown in table 4.13:

Table 4.13: Discounted Costs, Steam & Levelized cost of Steam

		Company A	Company B
MSW Value Chain	Drying cost (Ksh)	2,600,733.96	1,030,411.81
	Transport cost - Dandora (Ksh)	8,684,489.26	3,865,532.74
	Transport cost - Kangemi (Ksh)	9,053,615.16	3,819,035.47
Discounting Factor	Discount Rate (Percentage)	12%	12%
	Work Time (Years)	20.00	20.00
Discounted Figures	Discounted cost- Dandora (Ksh)	4,564,078.42	3,212,833.22
	Discounted cost-Kangemi (Ksh)	4,602,344.51	3101193.535
	Discounted Firewood cost (Ksh)	6,138,353.49	4,189,817.28
	Discounted steam (Kg)	3,091,471.21	1,383,285.94
Levelized Cost of Steam (LCOS)	Firewood LCOS (Ksh/Kg)	1.99	3.03
	waste LCOS- Dandora (Ksh/Kg)	1.48	2.32
	waste LCOS-Kangemi (Ksh/Kg)	1.49	2.24

Table 4.13 shows the total drying and transport costs of municipal solid waste (MSW) sourced from Dandora or Kangemi. The total cost was derived using Equation 3.2, which accounts for transportation expenses, while the drying cost was determined using Equation 3.7, which quantifies the energy required for moisture removal. the total drying & transport costs of municipal solid waste (MSW) sourced from Dandora or Kangemi. These costs reflect the reality that MSW often requires additional pre-processing to achieve optimal moisture content. By contrast, this research did not incorporate same drying or transport expenses in firewood cost, to keep the model as to what both companies are currently practicing in terms of their operations.

While both companies incur distinct drying and transportation expenses for MSW sourced from Dandora and Kangemi, Company A, operating at a larger scale, shows a slightly higher absolute transport cost for Kangemi at Ksh 9,053,615.16 than for Dandora at Ksh 8,684,489.26. Similarly, Company B exhibits a moderate gap between Dandora at Ksh 3,865,532.74 and Kangemi at Ksh 3,819,035.47 for transport costs. These figures show minimal variations despite the differences in distances.

This study employs a 12% discount rate, supported by Burgess & Zerbe (2011), who notes that rates in the 10–12% range reflect the social opportunity cost of capital for private-sector investments, accounting for risk and alternative returns relevant to boiler system investments. A 20-year lifespan was also adopted for this analysis, aligning with manufacturer estimates for firetube & water tube boilers under standard maintenance conditions (Powerhouse Combustion & Mechanical Corporation, 2025).

The comparative Levelized Cost of Steam (LCOS) for Companies A and B under varying feedstock firewood vs. MSW from Dandora and Kangemi, were calculated using the discounting costs and discounted steam produced. Figures 4.6 &4.7 below present the finding of the LCOS for company A and Company B respectively.

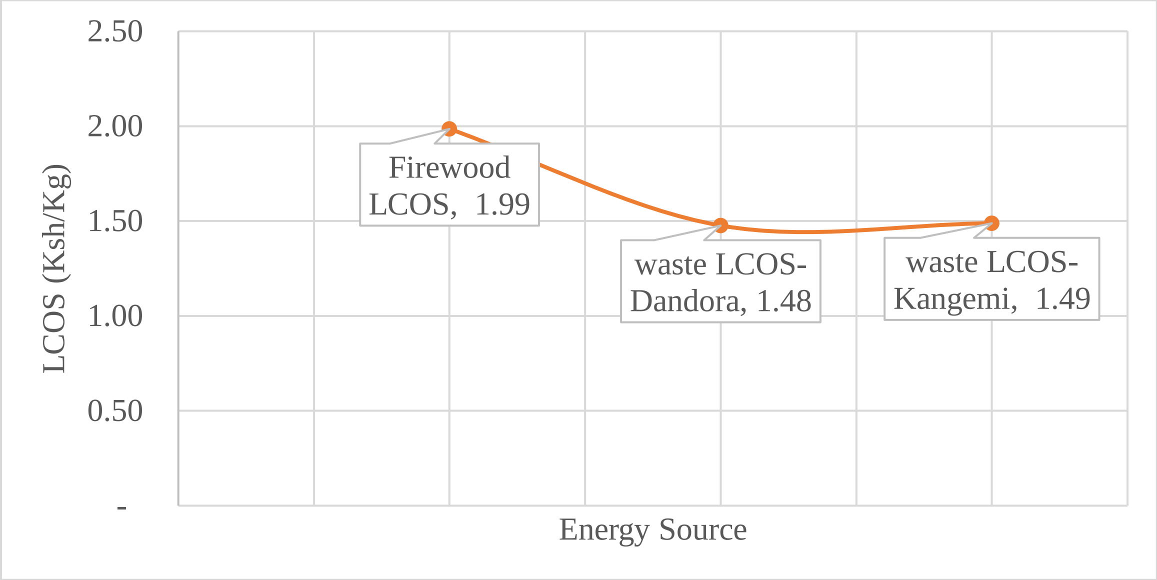


Figure 4.6: Company A: Levelized Cost of Steam from different sources

Data from table 4.13, were used to establish the LCOS based on equation 3.9. Figure 4.6 above compares the baseline scenario of firewood-driven steam generation against two proposed MSW-based alternatives from Dandora and Kangemi. The figure shows the Levelized Cost of Steam, where firewood serves as the benchmark. MSW from both sites offer a lower LCOS, even after factoring in additional drying and transport expenses. Company A's MSW LCOS ranges from 1.48–1.49 Ksh/kg versus 1.99 Ksh/kg for firewood.

This translates to a cost reduction of roughly 25% compared to firewood, a margin that remains robust even if one applies typical sensitivity ranges of ±10%. This difference can be attributed to the combined effect of reduced feedstock, cost of buying MSW vis-à-vis firewood and economies of scale. These factors outweigh the variation in transport distances between Dandora and Kangemi. This gives a good indicator for its potential as a cost-competitive resource.

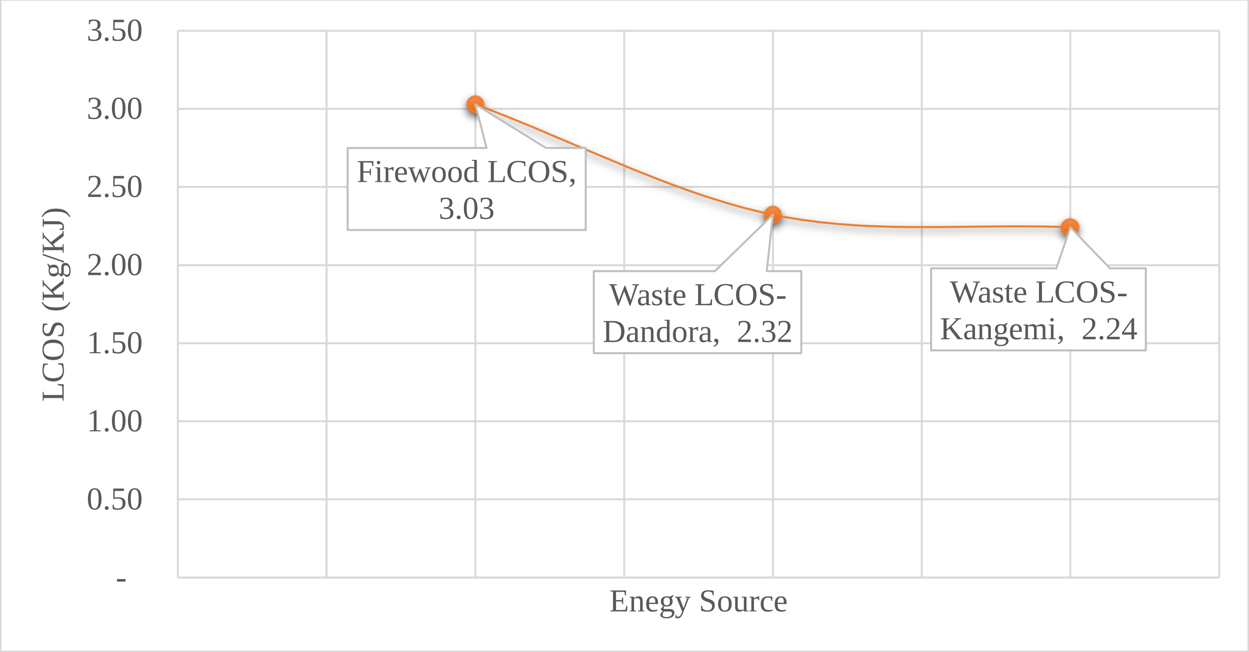


Figure 4.7: Company B: Levelized Cost of Steam from different sources

A similar analysis was done for Company B as shown in figure 4.7. Baseline levelized cost of steam (LCOS) using firewood stands at 3.03 Ksh/kg, whereas the MSW based options sourced from Dandora and Kangemi register 2.32 Ksh/kg and 2.24 Ksh/kg, respectively.

The data indicates a statistically significant reduction in LCOS with MSW, with Dandora offering a 23.4% decrease and Kangemi a 26.1% decrease compared to firewood. This suggests an economic case for adoption, with the difference exceeding typical confidence intervals of ±0.1 Ksh/kg for similar energy cost analyses, reinforcing the reliability of MSW as a cost-effective solution (Shah & Kaur, 2024). The slight LCOS variation between Dandora 2.32 Ksh/kg and Kangemi 2.24 Ksh/kg—a 3.4% difference of 0.08 Ksh/kg stems from variation of distances from the collection points to the company.

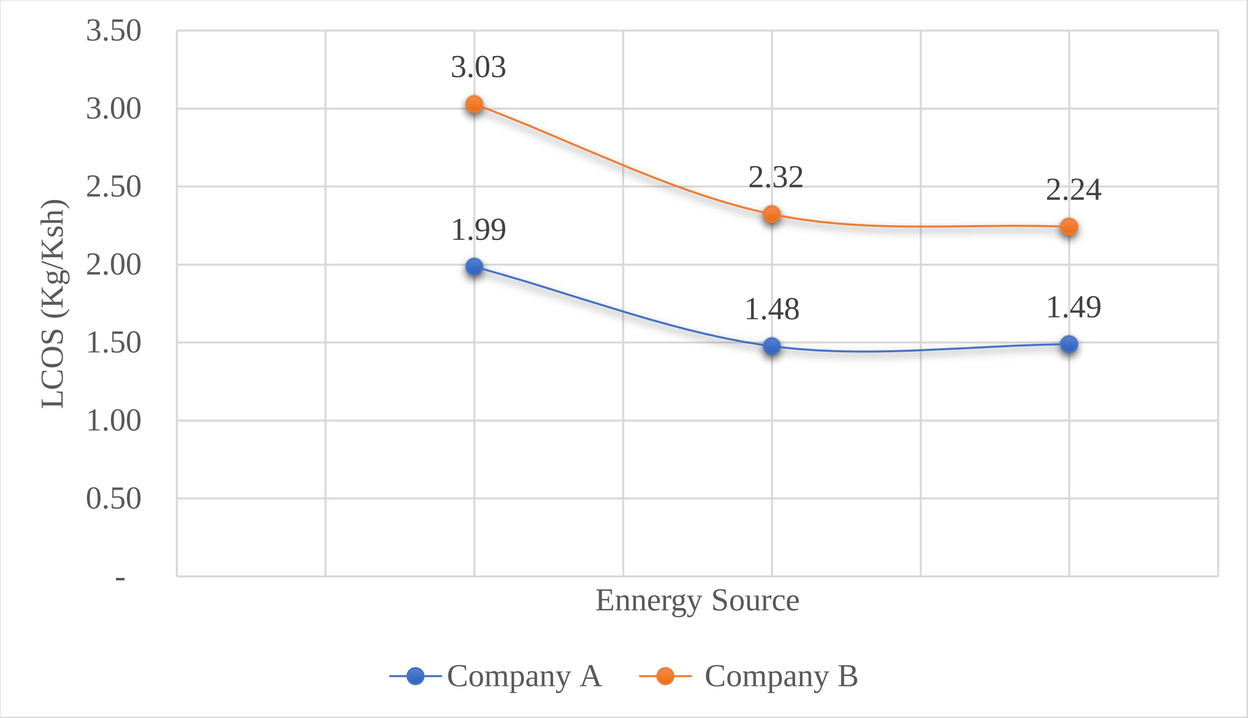


Figure 4.8: Company A&B: Levelized cost of Steam from different sources

In the combined chart figure 4.8 above Company A and B, generally trend downward as they shift from firewood to MSW, suggesting that Kangemi waste site offers the most cost-effective solution. Company A's is lower than Company B throughout, because of economies of scale and the operational differences between the two facilities. Company A operates consistently in intervals of 3 days while company B closes operations after 5pm. More continuous and large-scale steam demand in company A translates into better economies of scale and more efficient equipment utilization, hence the lower cost of steam per Kg. The most optimal LCOS for company A is 1.48 Ksh/Kg in Dandora and 2.24Ksh/Kg in Kangemi for Company B.

4.4.1 Scenario Analysis

This section represents the results of scenario analysis as described in table 3.1. In Scenario One, the associated cost of MSW was varied by 15% while in Scenario two, costs changed by 30%. The costs being subjected to this scenario analysis are the fixed buying cost (Ksh), the millage variable cost (Ksh/Km) and the tariffs.

The results of the Scenarios for company A and B are shown in Table 4.14 and 4.15 below:

Table 4.14: Scenario cost changes in company A

	Company A		
	Normal	Scenario 1 (15%)	Scenario 2 (30%)
Fixed cost (Buying cost)	48,300.00	55,545.00	62,790.00
Variable cost (Cost per Km)	120.00	138.00	156.00
Tariff (Ksh/KWh)	27.00	31.05	35.10
Drying cost (Ksh)	2,600,733.96	2,990,844.05	3,380,954.15
Transport Dandora (Ksh)	8,684,489.26	9,987,162.65	11,289,836.04
Transport Kangemi (Ksh)	9,053,615.16	10411657.43	11,769,699.71

Table 4.15: Scenario cost changes in company B

	Company B		
	Normal	Scenario 1 (15%)	Scenario 2 (30%)
Fixed cost (Buying cost)	48,300.00	55,545.00	62,790.00
Variable cost (Cost per Km)	120.00	138.00	156.00
Tariff (Ksh/KWh)	24.00	27.60	31.20
Drying cost (Ksh)	1,030,411.81	1,184,973.59	1,339,535.36
Transport Dandora (Ksh)	3,865,532.74	4,445,362.65	5,025,192.56
Transport Kangemi (Ksh)	3,819,035.47	4,391,890.79	4,964,746.11

The scenario analysis shows the cost changes in both drying and transport operations across Companies A and B. Company A, the drying cost increases from Ksh 2,600,733.96 in the Normal scenario to Ksh 2,990,844.05 under Scenario 1 to Ksh 3,380,954.15 under Scenario 2, which represents a 30% escalation. Similarly, the transport costs for Dandora and Kangemi exhibit proportional increases; Transport Dandora rises from Ksh 8,684,489.26 to Ksh 9,987,162.65 and then to Ksh 11,289,836.04. while Transport Kangemi moves from Ksh 9,053,615.16 to Ksh 10,411,657.43 and ultimately to Ksh 11,769,69.71

In Company B, the analysis follows a similar proportionate increase reflective of the baseline adjustments. The drying cost increases from Ksh 1,030,411.81 in the Normal scenario to Ksh

1,184,973.59 and further to Ksh 1,339,535.36. Similarly, Transport Dandora and Transport Kangemi costs increase from Ksh 3,865,532.74 and Ksh 3,819,035.47, respectively.

As drying and transport expenses rise, the levelized cost of steam will be subsequently affected. The results of the costs are given in figures 4.9 and 4.10 below showing the trend,

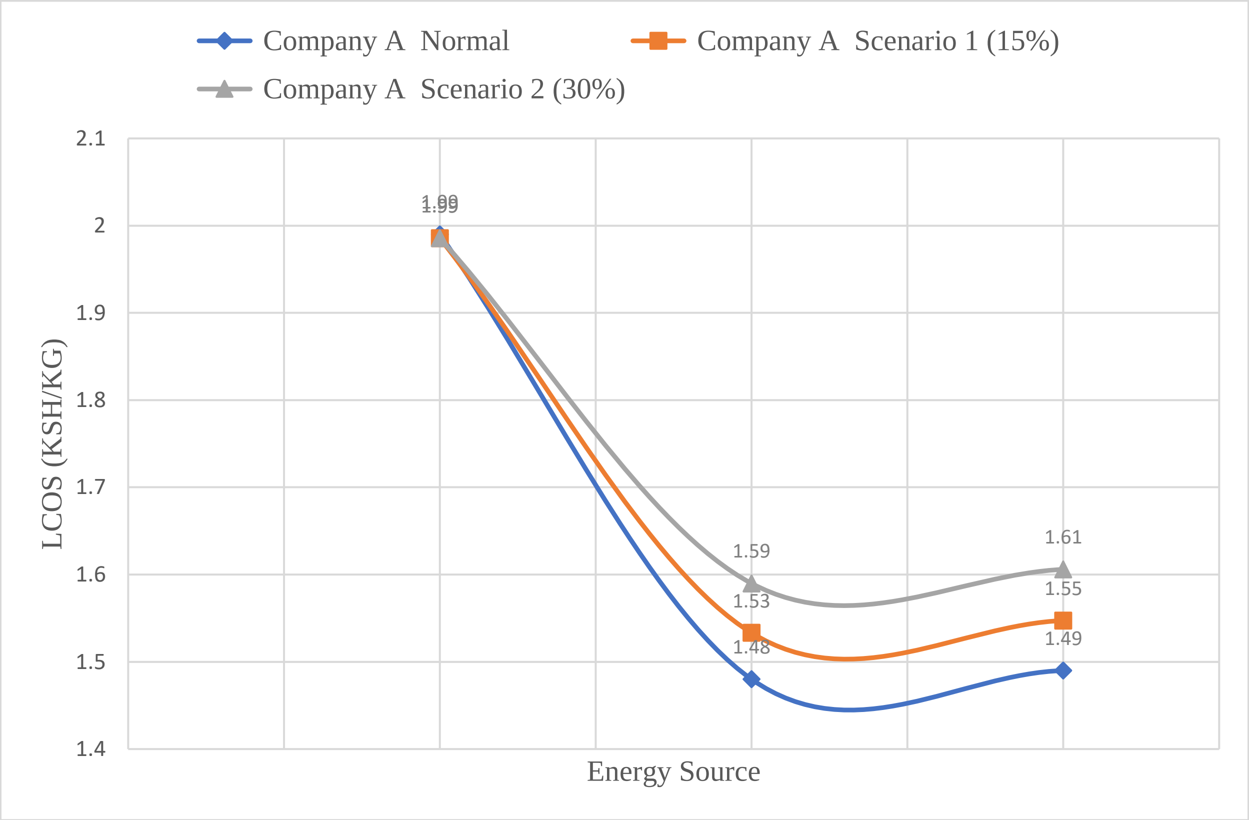


Figure 4.9: Company A: LCOS under Normal, Scenario 1 & 2

In Figure 4.9, Company A's LCOS under Normal, 15%, and 30% cost-increment scenarios exhibit a clear upward from the normal cost (Blue line). The costs under both scenarios are still below current LCOS using firewood.

In each scenario, Dandora is the gives the lowest cost of LCOS. All costs in the scenario analysis are below 2Ksh/Kg of steam. The parallel nature of the three curves: Normal, 15% increase, and 30% increase demonstrates the uniformly in cost escalations in market shifting dynamics.

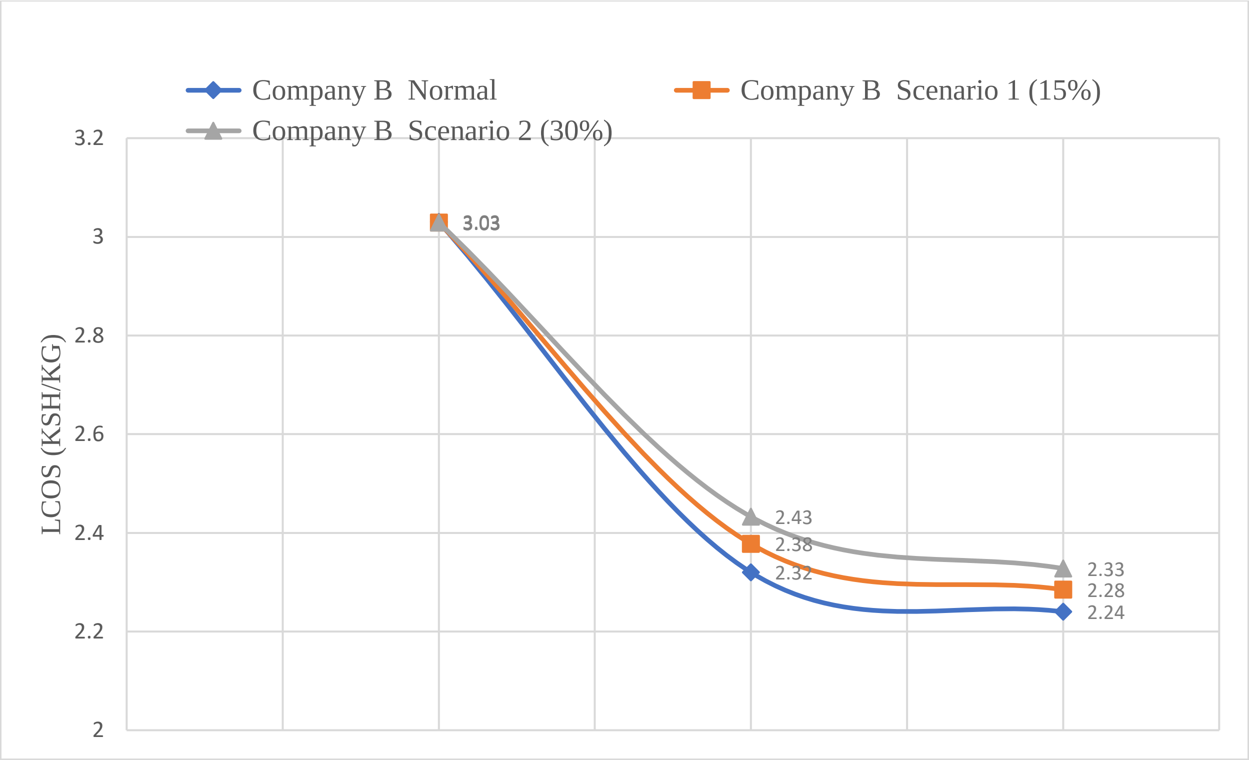


Figure 4.10: Company B: LCOS under Normal, Scenario 1 & 2

Figure 4.10 above shows all three curves descend in a consistent manner, reflecting the replicability of the model. Company B's LCOS under Normal, Scenario 1 (15%), and Scenario 2 (30%), shows a notable cost increase, consistently, but lower than the firewood LCOS.

The parallelism of the curves suggests that the model increment affects costs almost consistently, considering the difference in the distances from Kangemi and Dandora. The tight clustering near Kangemi data point - all curves converging around 2.24 Ksh/kg indicates, Kangemi is the most cost effective and cheapest source for steam generation. Under Scenarios 1 and 2 the cost is still cheaper than the normal firewood LCOS, despite the increment in costs

The LCOS appears inelastic, as cost increments due to transport and drying. The demand for steam was considered constant, throughout. Despite a 30% cost shift, the LCOS remains below the biomass LCOS, reinforcing its inelasticity, in terms of price sensitivity.

CHAPTER 5: CONCLUSION AND RECCOMENDATION

5.1 Conclusion

This study set out to model municipal solid waste use for steam generation for industrial and hospitality sector. These were achieved through evaluating the calorific values of biomass and municipal solid waste (MSW), analyzing the existing techniques used for modeling municipal solid waste, modelling of transport and treatment in municipal solid waste in steam generation and conducting a techno-economic analysis of MSW as feedstock for steam generation. This section presents the summary and conclusion of the study findings.

i. The firewood calorific values for Company A, B and MSW were determined to be 17.43MJ/Kg, 17.34MJ/Kg, and 23.08MJ/Kg respectively. This represents a 37% increase in energy concentration per KJ in the feedstock fuel, as illustrated in figure 4.3. It can therefore be concluded that the proposed source of fuel for steam generation is viable because it guarantees more energy decimation per Kg.
ii. Assessment of distance of the waste collection point to Company A and B in the proposed model revealed that distance influences the cost of steam, despite assumption of same variable cost per Km and same cost of buying MSW. This is observed in all scenario analysis. It can therefore be concluded that the distance of waste collection point has an influence in the overall cost of steam per Kg.
iii. The difference between energy demands determined by the proposed model showed a 27% reduction in the Kg of energy source to get the same amount of energy, in both companies A and B. The findings reveal that MSW is an appropriate energy source, with a reduced demand for storage space.
iv. The model came up with a drying analysis that showed a cost of 2.6 million and 1.03 million in company A and B. It can therefore be concluded that despite the drying process optimizing the combustion properties of MSW, it is a costly operation
v. Assessment of the LCOS, resulting from the proposed model and that for Scenarios One and Two showed that the cost of steam from MSW is cheaper than using firewood. The findings reveal that the optimal cost for company A is 1.48 Ksh/Kg in Dandora 2.24Ksh/Kg in Kangemi for Company B.

vi. The Scenario analysis conducted, showed the LCOS under both scenarios was lower than the current LCOS. Despite economic shocks of 15% and 30% market increase the cost was still lower. This led to the conclusion that the use of MSW can source of fuel can withstand eventualities that come with the value chains of its use such as transportation and drying.

5.2 Recommendations

The following are the recommendations for areas related to this study that need further investigation;

i. In the Calorific value evaluation of MSW, the waste characterization was assumed to be uniform across zone 1-3 in Nairobi County. Localized waste characterization studies to capture the heterogeneity of MSW across different urban zones, should be conducted. This would help refine the model by considering variations in energy demand in Kg based on the waste produced

ii. This study primarily examined incineration through boilers; however, expanding the techno-economic analysis to include alternative waste-to-energy conversion pathways could offer a more comprehensive perspective. A comparative evaluation of gasification, pyrolysis, and anaerobic digestion would help identify the most efficient and sustainable methods for energy recovery, optimizing both economic feasibility and environmental impact.

iii. The literature for MSW utilization focused on the technical aspect alone. Future work on examining the socio-economic and policy implications such stakeholder acceptance, regulatory frameworks, and incentive structures on adoption of MSW-based steam generation, would give a full realistic view and enhance policy adjustments.

iv. The distances considered in the transport model were assumed to be linear and did not consider routing consideration. Future work should investigate the spatial analysis of the impact of transport distances, routing efficiencies, and geographic factors to fine-tune the transport model.

REFERENCES

Kimata, D., Kweyu, D., & Ogutu, F. (2019). A Spatial Analysis of Unplanned and Mushrooming Dumpsites and Environmental Governance in Nairobi County . *International Knowledge sharing Platform, 9*(10), 10.

Abbas, H., Uzair , M., Khan , H., & Hussain, S. (2020). Abbas, H., Uzair, M. M., Khan, H., Hussain, S., & Topi, D. S. Designing of a fire tube boiler. *Ghulam Ishaq Khan Institute of Engineering Sciences and Technology.*

Abdulrahman, D., Johannes, R., Franz, H., & Sabrina, D. (2022). Techno-Economic Comparison of Steam Generation Systems with Industrial Heat Pumps. *Proceedings of EuroSun 2022 - ISES and IEA SHC International Conference on Solar Energy for Buildings and Industry* (p. 12). Austria: Research Gate. doi:10.18086/eurosun.2022.05.02

Africa Energy Outlook. (2019). *Africa Energy Outlook.* France: International Energy Agency.

Amulen, J., Kasedde, H., Serugunda, J., & Lwanyaga, J. (2022). The potential of energy recovery from municipal solid waste in Kampala City, Uganda by incineration. *Energy Conversion and Management: X, 14*, 100204. doi:10.1016/j.ecmx.2022.100204

Atul , K., & Samadder, S. R. (2017). A review on technological options of waste to energy for effective management of municipal solid waste. 69. doi:10.1016/j.wasman.2017.08.046.

Basu, S., & Debnath, A. (2019). *Power plant instrumentation and control handbook : a guide to thermal power plants.* London: Academic Press, an imprint of Elsevier.

Belyakov, N. (2019). Geothermal energy; . In N. Belyakov, *Geothermal energy; Sustainable Power Generation* (pp. 475-600). Academic Press. doi:10.1016/b978-0-12-817012-0.00034-7

Boiler learn. (2023, 12 2). *cochran boiler – diagram, working, parts, construction, advantage, disadvantage*. Retrieved from Boiler learn: https://boilerlearn.com/cochran-boiler/

Bridgwater, T. (2012). Review of fast pyrolysis of biomass and product upgrading. *Biomass and Bioenergy 38.*, 68-94. doi:10.1016/j.biombioe.2011.01.048.

Brodowicz, M. (2024, March 19). *Fire Tube Boiler and How It Works Report*. Retrieved from https://aithor.com/essay-examples/fire-tube-boiler-and-how-it-works-report

Burgess, D. F., & Zerbe, R. O. (2011). .Appropriate Discounting for Benefit-Cost Analysis. *Journal of Benefit-Cost Analysis.*, 2. 2-2. doi:10.2202/2152-2812.1065.

Castells, B., Tascón, A., Amez, I., & Fernandez-Anez, N. (2023, 8 17). Influence of Particle Size on the Flammability and Explosibility of Biomass Dusts: Is a New Approach Needed? *Fire Technology*, 2989-3025. doi:https://doi.org/10.1007/s10694-023-01468-7

Deghal Cheridi, A., Loubar, A., Dadda, A., & Bouam, A. (2019, 10 5). Modeling and simulation of a natural circulation water-tube steam boiler. *SN Applied Sciences, 1*(11), 15. doi:10.1007/s42452-019-1452-x

Elgandelwar, A., Jha, R., & Lele, M. (2020). Study of circulation ratio for natural circulation in water-tube boiler at different operating conditions. *Journal of physics. Conference series*, 9. doi:10.1088/1742-6596/1473/1/012026

Elkelawy, M. A.-R.-e.-m. (2022). Experimental investigation on emission and combustion characteristics of an industrial burner using biogas co-fired with diesel and biodiesel. . *Egyptian Sugar Journal*, 19(0), 29–43. . doi:10.21608/esugj.2022.164403.1025

Eltamaly, A., & Mohamed, M. (2018). Optimal Sizing and Designing of Hybrid Renewable Energy Systems in Smart Grid Applications. *Advances in Renewable Energies and Power Technologies*, 231-313. doi:10.1016/b978-0-12-813185-5.00011-5

Er Amrit, K. (2021, 6 30). *Cornish Boiler: Definition, Construction or Parts, Working Principle, Advantages, Application* . Retrieved from https://themechanicalengineering.com/cornish-boiler/

Eriisa Yiga Paddy, Beckley Victorine Namondo, Fopah-Lele, A., Josepha Foba-Tendo, Fuseini Seidu Ibrahim, & Tanyi, E. (2024, 5 25). Assessment of the energy potential of municipal solid waste: A case study of Mussaka dumpsite, Buea Cameroon. *Bioresource technology reports, 25*, 101784-101784. doi:10.1016/j.biteb.2024.101784

Filip, K., & Niko, S. (2013). Advances in Internal Combustion Engines and Fuel Technologies. In K. Filip, & S. Niko, *Advances in Internal Combustion Engines and Fuel Technologies* (p. 320). Malaysia : IntechOpen. doi:DOI: 10.5772/55497

Florence , B. A., & Sabine , A. E. (2023). Solid Waste Management in the Context of the Waste Hierarchy and Circular Economy Frameworks: An International Critical Review. *Integrated Environmental Assessment and Management.*, 20.

Food and Agriculture Organization (FAO). (1986). *Wood gas as engine fuel*. Retrieved from FAO Forestry Paper 72: https://www.fao.org/4/t0512e/t0512e00.htm

Gilbert, N., Ziqiang, Y., & Hongzhi, M. (2022, 9 2). Current situation of solid waste management in East African countries and the proposal for sustainable management. *African Journal of Environmental Science and Technology, 15*(1), 15. doi:10.5897/ajest2020.2911

Google Maps. (2025, 1 1). *Nairobi City, NBO Map*. Retrieved from Google Maps: https://www.google.com/maps

Goyal, A., Pandey, D., Jain, S., Tyagi, M., Agarwal, J., & Jain, S. (2017, 4 27). Development of Decision Model for Power Generation from Carbonized Food Waste. *Waste and Biomass Valorization, 9*(10), 1955-1960. doi:10.1007/s12649-017-9948-3

Hlaba, A., Rabiu, A., & Osibote, O. (2016). Thermochemical Conversion of Municipal Solid Waste — An Energy Potential and Thermal Degradation Behavior Study. *International Journal of Environmental Science and Development, 7*(9), 661-667. doi:10.18178/ijesd.2016.7.9.858

Igniss Energy. (2025, 1 1). *Calorific value of waste*. Retrieved from Igniss EnergyIncineration Technology: https://www.igniss.com/calorific-value-waste

Industrial Quick Search. (2023). *Industrial Quick Search*. Retrieved from Water Tube Boilers: www.iqsdirectory.com

Ivanov, N., Abilmagzhanov, A., Kholkin, O., & Adelbaev, I. (2024, 1 2). Comprehensive Study of Energy Characteristics and Biohazard Assessment of Municipal Solid Waste from the Landfill of the City of Atyrau. *Clean technologies, 6*(1), 49-61. doi:10.3390/cleantechnol6010004

J Peredo , D. Silió, M. Mañana, A. Ortiz, C. J. Renedo, & S. Pérez. (2006). Comparison of energy potential of the eucalyptus globulus and the eucalyptus nitens. *Renewable Energy and Power Quality Journal, Vol. 4 No. 1 (2006)*, 285-292. doi:10.24084/repqj04.285

J., M., S., D., & A.A., M. (2022). Energy storage systems: A review. *Keai Publishing*, 51. doi:10.1016/j.enss.2022.07.002

Jena, M., & Kar, B. (2019, 11 11). Stages and Methods for Cleaning Large Secondary Data Using R. *Methodological Issues in Management Research: Advances, Challenges, and the Way Ahead*, 285-304. doi:10.1108/978-1-78973-973-220191018

JICA. (2010). *The preparatory survey for integrated solid waste management in Nairobi City.* Nairobi: Japan International Cooperation Agency (JICA) , CTI Engineering International CO., LTD, NJS Consultants CO., LTD. Retrieved from https://openjicareport.jica.go.jp/pdf/12005468_01.pdf)

Jisu, B., Lee, S., Kyuyeon, K., Jun-gu, K., & Taewan, J. (2024). Reassessment of lower heating value calculations for municipal solid waste incineration facilities in South Korea. *Energy, 293*, 130669-130669. doi:https://doi.org/10.1016/j.energy.2024.130669

Kenya Bureau of Standards. (2021). *Solid biofuels - Fuel specifications and classes.* Nairobi: Kenya Bureau of statistics.

Kenya National Bureau of Statistics. (2022). *ECONOMIC SURVEY 2022.* Nairobi: Kenya National bureau of statistics.

Khaleel, S. H., Basim, I., Bin, A. H., & Khalil, I. (2022). Energy and exergy analysis of the steam power plants: A comprehensive review on the Classification, Development, Improvements, and configurations. *Ain Shams Engineering, 13*(3), 22. doi:10.1016/j.asej.2021.11.009

Kiang, Y.-H. (2018). Fuel Property Estimation and Combustion Process Characterization. In Y.-H. Kiang, *Fuel Property Estimation and Combustion Process Characterization* (pp. 313-362). New York: Academic Press. doi:10.1016/b978-0-12-813473-3.00009-x

KNBS, K. N. (2023). *Economic Survey 2023.* Nairobi: Kenya National Bureau of Statistics.

Kumar, A. (2020, 7 22). *Locomotive Boiler: Definition, Parts, Working Principle, Advantages, Disadvantages, Application*. Retrieved from Themechanicalengineering.com: https://themechanicalengineering.com/locomotive-boiler/

Lahijani, A., & Eris E, S. (2018). Evaluating the Effect of Economizer on Efficiency of the Fire Tube Steam Boiler. *Innovative Energy & Research*, 5. doi:10.4172/2576-1463.1000193

Lean Energy. (2025, 1). *Boiler Conversion*. Retrieved from Lean Energy Solution:Boiler Conversion: https://www.leansolutions.co.ke/boiler-conversion.php

Manoj , S., Nandeshwar , L., & Bharat , N. (2020). Plastic Waste as an Alternate Fuel. *International Journal of Engineering Research and Technology (IJERT)*.

Mapereka Francis Chagunda, Tabukeli Musigi Ruhiiga, & Palamuleni, L. (2023, 7 11). Evaluation of energy generation potential from municipal solid waste in the North-West province, South Africa. *International Journal of Renewable Energy Development, 12*(5), 832-841. doi:10.14710/ijred.2023.52248

Mark. (2024, February 22). *Steam Boiler Trends in Kenya*. Retrieved from https://spenomatic.net/the-future-of-steam-boilers-trends-and-innovations-in-kenya/

Md Naim Hossain, & Ghosh, K. (2023). Effect of peripheral nonuniform distribution of furnace heat flux on thermo-hydraulic characteristics and design of riser downcomer circuit of natural circulation boiler. *Applied thermal engineering*, 10. doi:10.1016/j.applthermaleng.2023.120135

Mechanical Engineering. (2016, 2 10). *Types of boilers*. Retrieved from Mechanical Engineering - Construction & Maintenance: https://mechanicalfieldexperience.blogspot.com/2016/02/types-of-boilers.html

Ministry of Energy. (2020). *Bioenergy Strategy 2020-2027.* . Nairobi: Ministry of Energy. Retrieved from Repository.kippra.or.ke. https://repository.kippra.or.ke/handle/123456789/3017

Ministy of Enviroment and Foresty. (2020). *The National Forest Reference Level for REDD+*. Nairobi: Ministy of Enviroment and Foresty.

Mohd, & Roslina, M. (2023). Safeguarding Boiler Operations Tools in Malaysia with Hazard Identification, Risk Assessment, and Risk Control. . *International Journal of Business and Technology Management, 5*, 137–145. Retrieved from https://myjms.mohe.gov.my/index.php/i

Mohsen, S., Majid, A., Mohammad Ali, M., Marjan, H., Ebrahim, S., & Mehrzad, S. (2023, 1 1). Technical-Economic Analysis of Energy Efficiency Solutions for the Industrial Steam System of a Natural Gas Processing Plant. Sustainability,. *Sustainability, 15*(20), 24. doi:10.3390/su152014995

Moya, D., Aldás, C., López, G., & Kaparaju, P. (2017, 10). Municipal solid waste as a valuable renewable energy resource: a worldwide opportunity of energy recovery by using Waste-

To-Energy Technologies. *Energy Procedia, 134*, 286-295. doi:10.1016/j.egypro.2017.09.618

Mugo, S. (2019). *Assessment of Solid Waste Management at Wakulima Market in Nairobi City, Kenya.* Nairobi: university of nairobi. Retrieved from http://erepository.uonbi.ac.ke/handle/11295/106893

Munich Re Company. (2024). *What is the True Cost of Steam?* . Retrieved from Www.hsb-Ats.com.: https://www.hsb-ats.com/en/industrial-iot/steam-as-a-service/steam-costs/what-is-the-true-cost-of-steam-.html

Mustia, D., Edy, S., & Nurul, A. (2021, 11 1). Analysis of waste composition as a source of refuse-derived fuel in Cilacap. *IOP conference series, 896*(1), 012063-012063. doi:10.1088/1755-1315/896/1/012063

Natalie , J., & Geert , C. v. (2019). Waste Management. In *The Oxford Handbook of Comparative Environmental Law.* Oxford.

Ndagi, A., Mohammed, A., Saleh, A., Shuaibu, A., Hassan, I., Abubakar, S., . . . Jagaba, A. (2023). Proximate analysis of waste-to-energy potential of municipal solid waste for sustainable renewable energy generation. *Ain Shams Engineering Journal*, 9. doi:10.1016/j.asej.2023.102357

Neto, L. V. (2020). MODELING COSTS IN SOLID WASTE TRANSPORTATION. *International Online* (p. 10). Rio de Janeiro: ResearchGate. Retrieved from https://www.researchgate.net/publication/345752018_MODELING_COSTS_IN_SOLID_WASTE_TRANSPORTATION

Nyaga Beth. (2023, September 5th). *kbc.co.ke*. Retrieved from Schools in Kenya turn to steam as alternative low-carbon energy fuel source - Kbc.co.ke.: https://www.kbc.co.ke/schools-in-kenya-turn-to-steam-as-alternative-low-carbon-energy-fuel-source/

Nyika, J., & Dinka, M. (2022). Converting solid waste materials to Energy: A review. *Materials Today: Proceedings, 57*, 964-968. doi:10.1016/j.matpr.2022.03.240

Oludolapo, A. O., & Moses Jeremiah, K. B. (2019). The Potential of Grid Power Generation from Municipal Solid Waste for Nairobi City. *2nd African International Conference on Industrial Engineering and Operations Management* (p. 17). Zimbabwe: IEOM Society International . Retrieved from https://www.researchgate.net/publication/349350162_The_Potential_of_Grid_Power_Generation_from_Municipal_Solid_Waste_Case_of_Nairobi_City

Omari, A., Kichonge, B., John, G., Njau, K., & Mtui, P. (2014, 6 1). Potential of municipal solid waste, as renewable energy source : a case study of Arusha, Tanzania. *International Journal of Renewable Energy Technology Research*, 11. Retrieved from https://dspace.nm-aist.ac.tz/handle/20.500.12479/350

Perera, F. (2018). Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist. *International Journal of Environmental Research and Public Health, , 15*(1), 16. doi:https://doi.org/10.3390/ijer

Powerhouse Combustion & Mechanical Corporation. (2025, 1 1). *Boiler Services*. Retrieved from Mechanical & Combustion Powerhouse: https://powerhouse-combustion.com/can-my-boiler-last-for-30-years/

Rayaprolu, K. (2013). *Boilers : a practical reference.* India: Crc Press. Retrieved from https://www.routledge.com/Boilers-A-Practical-Reference/Rayaprolu/p/book/9781138073272

Roger , R. M. (2013). *Handbook of Wood Chemistry and Wood Composite.* CRC Press.

Savree. (2024, 1 1). *Savree*. Retrieved from Watertube Boilers Explained: https://www.savree.com/en/encyclopedia/watertube-boiler

Shah , M. P., & Kaur, P. (2024). *Biomass Energy for Sustainable Development.* Boca Raton: CRC Press. doi:https://doi.org/10.1201/9781003406501

Shokri, A., & Mahdi, S. (2023, 10 1). Principles, operational challenges, and perspectives in boiler feedwater treatment process. *Environmental Advances, 13*, 11. doi:10.1016/j.envadv.2023.100389

Świątkowski, T., Kalisz, S., & Wnorowska, J. (2022). An innovative conversion of a district heating water-tube boiler for cogeneration of electricity and heat. *Results in Engineering, 13*(100350), 9. doi:https://doi.org/10.1016/j.rineng.2022.100350

Takase, M., Kipkoech, R., & Paul , K. E. (2021). A comprehensive review of energy scenario and sustainable energy in Kenya. *Fuel Communications, 7*(100015), 13. doi:https://doi.org/10.1016/j.jfueco.2021.100015

Teir, S. (2003). *Steam Boiler Technology e-book* (2.43 ed.). Helsinki: Helsinki University of Technology.

Tesfaldet , G., Oyedun, O. A., & Hui, D. (2013). Optimum biomass drying for combustion – A modeling approach. *Proceedings of the ICE - Energy*, Energy. 53. 67–73. doi:10.1016/j.energy.2013.03.004.

Thermodyne Engineering Systems. (2017, 1 31). *What is a Lancashire Boiler?* Retrieved from Thermodyne Engineering Systems: https://thermodyneboilersblog.wordpress.com/2017/01/31/what-is-a-lancashire-boiler/

ThiKimOanh, L., Bloemhof-Ruwaard, J., van Buuren, J., van der Vorst, J., & Rulkens, W. (2015, 3 4). Modelling and evaluating municipal solid waste management strategies in a mega-city: The case of Ho Chi Minh City. *Waste Management & Research, 33*(4), 370-380. doi:10.1177/0734242x15572177

TIlahUn , h. n., abDhalah , K., IsabElla , a., Dickson , A., & Kanyiva, M. (2017). An assessment of the evolution of Kenya's solid waste management policies and their implementation in Nairobi and Mombasa: analysis of policies and practises. *SCRIBD*, 18.

Trindade, A., Palacio, J., González, A., Rúa Orozco, D., Lora, E., Renó, M., & del Olmo, O. (2018, 2). Advanced exergy analysis and environmental assesment of the steam cycle of an incineration system of municipal solid waste with energy recovery. *Energy Conversion and Management, 157*, 195-214. doi:https://doi.org/10.1016/j.enconman.2017.11.083

Trust, C. (2014, March 1). *Energy efficiency opportunities in hospitality: A report on fuel substitution strategies*. Retrieved from Carbon Trust: https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/energy-efficiency-guide-hospitality-sector

Woldegebriel, A. A., & Amona, T. A. (2022, May). Characterization of Municipal Solid Waste for Energy Content. *Strad Research*, 14. doi:https://doi.org/10.37896/sr9.4/026

World Bank. (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development.* Washington D.C: World Bank. doi:https://doi.org/10.1596/978-1-4648-1329-0

Yazdani, S., Salimipour, E., & Moghaddam, M. (2020). A comparison between a natural gas power plant and a municipal solid waste incineration power plant based on an emergy analysis. *Journal of Cleaner Production*, 20. doi:10.1016/j.jclepro.2020.123158

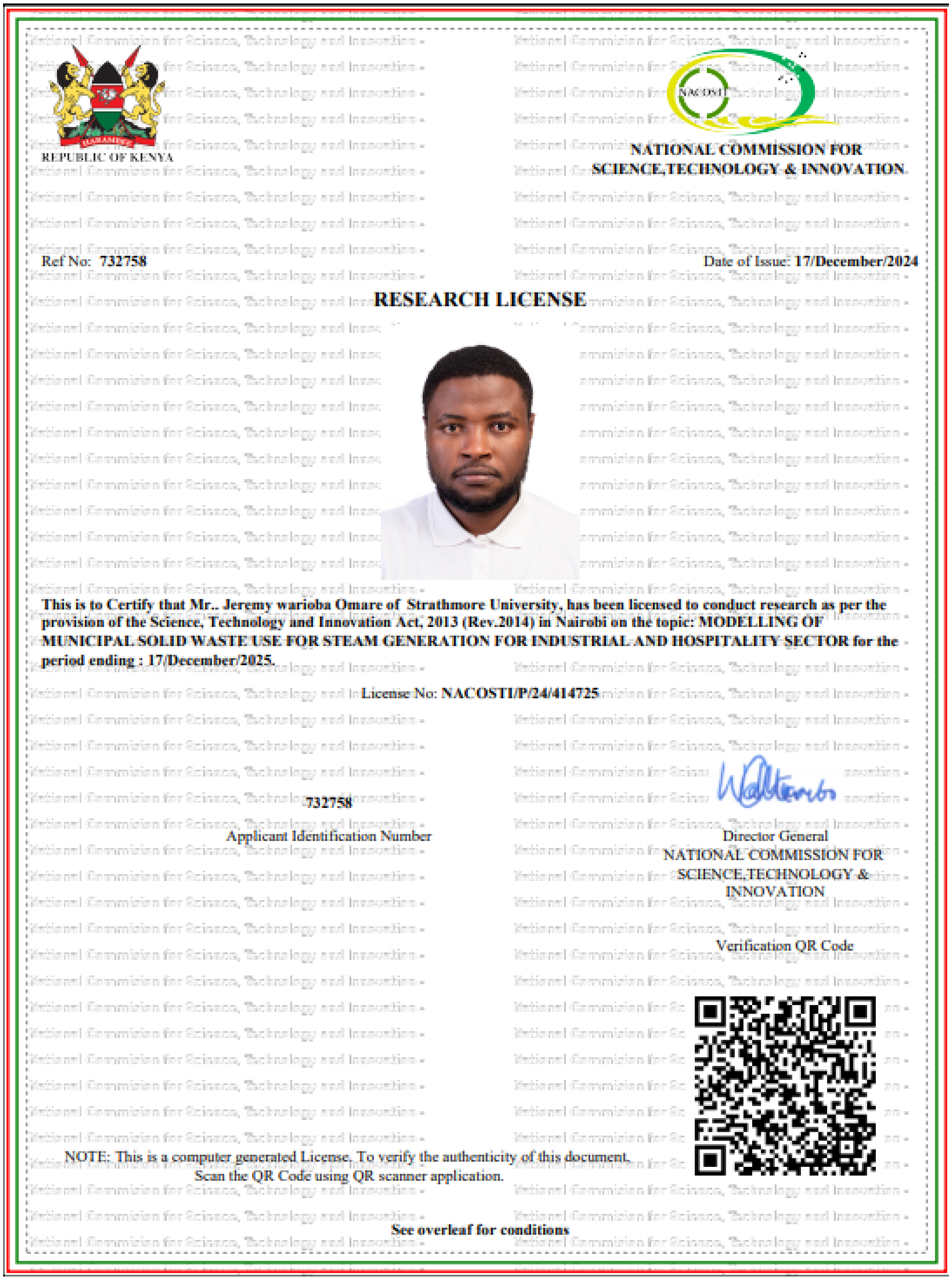
APPENDICES

Appendix A: Data collected: Company A & B

Company A		Company B	
Firewood (kg)	**Water (liters)**	**Firewood (kg)**	**Water (liters)**
14,563.00	63,700.00	6,377.80	17,084.00
11,984.00	63,500.00	6,454.40	17,802.00
10,924.00	71,000.00	6,587.60	16,574.00
12,093.00	59,244.00	6,090.50	18,028.00
6,694.00	17,669.00	5,941.80	18,125.00
6,870.00	62,861.00	6,070.20	16,088.00
14,010.00	61,690.00	6,241.40	17,664.00
14,146.00	51,297.00	4,742.80	13,573.00
13,319.00	46,002.00	5,794.00	16,545.00
14,184.00	48,213.00	6,338.90	18,700.00
12,764.00	41,990.00	6,180.00	18,911.00
16,061.00	61,856.00	6,275.80	19,455.00
13,606.00	50,188.00	6,579.80	19,513.00
15,614.00	49,754.00	6,771.70	19,367.00
15,473.00	50,571.00	6,680.00	19,049.00
7,920.00	32,659.00	5,012.00	14,787.00
7,768.00	35,744.00	4,854.70	14,370.00
11,913.00	38,738.00	5,640.00	17,261.00
13,736.00	38,738.00	5,959.30	17,580.00
9,056.00	30,249.00	5,735.70	17,494.00
13,658.00	44,638.00	5,390.90	16,712.00
9,890.00	37,476.00	6,301.60	19,262.00
12,399.00	41,063.00	6,053.50	19,129.00
13,625.00	44,792.00	5,359.50	16,936.00
11,786.00	30,621.00	5,909.70	18,320.00
20,191.00	45,081.00	4,586.80	14,036.00
15,465.00	65,801.00	5,562.10	16,408.00
15,455.00	57,613.00	5,036.30	15,411.00
16,144.00	56,576.00	5,142.80	15,737.00
18,331.00	65,126.00	4,588.90	14,682.00
19,045.00	55,625.00	5,600.00	17,582.00
17,426.00	49,152.00	5,845.90	17,304.00
9,505.00	48,185.00	5,509.50	16,308.00
13,066.00	58,838.00	5,408.80	17,092.00
13,705.00	60,870.00	5,603.20	17,146.00
13,298.00	61,670.00	5,860.80	17,662.00
16,483.00	60,964.00	5,689.80	17,980.00
17,150.00	63,553.00	5,519.60	16,338.00
15,847.00	58,344.00	5,742.00	18,174.00
11,547.00	57,210.00	5,351.20	16,910.00
16,705.00	61,851.00	5,516.30	16,880.00
13,104.00	71,062.00	5,684.00	16,825.00

12,840.00	35,869.00	5,922.00	18,149.00
13,388.00	28,560.00	5,225.30	16,512.00
13,182.00	37,487.00	5,624.00	17,210.00
13,203.00	37,559.00	5,473.00	16,235.00
9,132.00	22,564.00	5,400.00	15,949.00
15,140.00	50,461.00	5,974.40	17,624.00
11,867.00	58,511.00	5,609.20	16,603.00
14,288.00	54,888.00	5,760.40	17,051.00
14,147.00	61,769.00	5,132.30	15,705.00
13,028.00	57,379.00	5,536.20	16,387.00
9,031.00	23,717.00	4,910.10	14,534.00
15,157.00	55,807.00	4,198.10	13,266.00
21,416.00	62,050.00	4,436.00	13,544.00
18,323.00	55,081.00	5,032.60	14,897.00
		5,161.40	15,278.00
		4,928.80	12,646.00
		4,906.40	14,523.00
	-	5,130.00	15,698.00
		5,005.80	15,318.00

Appendix B: National Commission for Science, Technology and Innovation (NACOSTI) research certificate



REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **732758**

Date of Issue: **17/December/2024**

RESEARCH LICENSE

This is to Certify that Mr.. Jeremy warioba Omare of Strathmore University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nairobi on the topic: MODELLING OF MUNICIPAL SOLID WASTE USE FOR STEAM GENERATION FOR INDUSTRIAL AND HOSPITALITY SECTOR for the period ending : 17/December/2025.

License No: **NACOSTI/P/24/414725**

732758

Applicant Identification Number

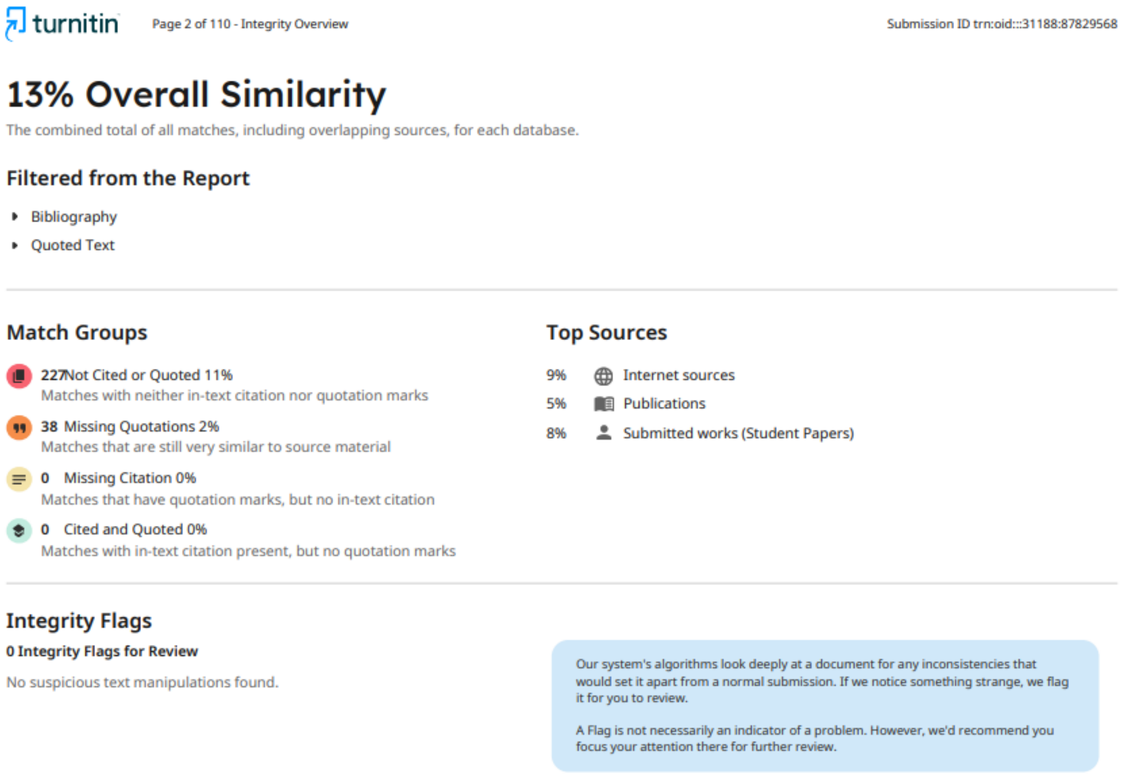
Director General
NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY &
INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document,
Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix C: Plagiarism report



Page 2 of 110 - Integrity Overview

Submission ID trn:oid:::31188:87829568

13% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Filtered from the Report

- Bibliography
- Quoted Text

Match Groups

227 Not Cited or Quoted 11%
Matches with neither in-text citation nor quotation marks

38 Missing Quotations 2%
Matches that are still very similar to source material

0 Missing Citation 0%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

9%	Internet sources
5%	Publications
8%	Submitted works (Student Papers)

Integrity Flags

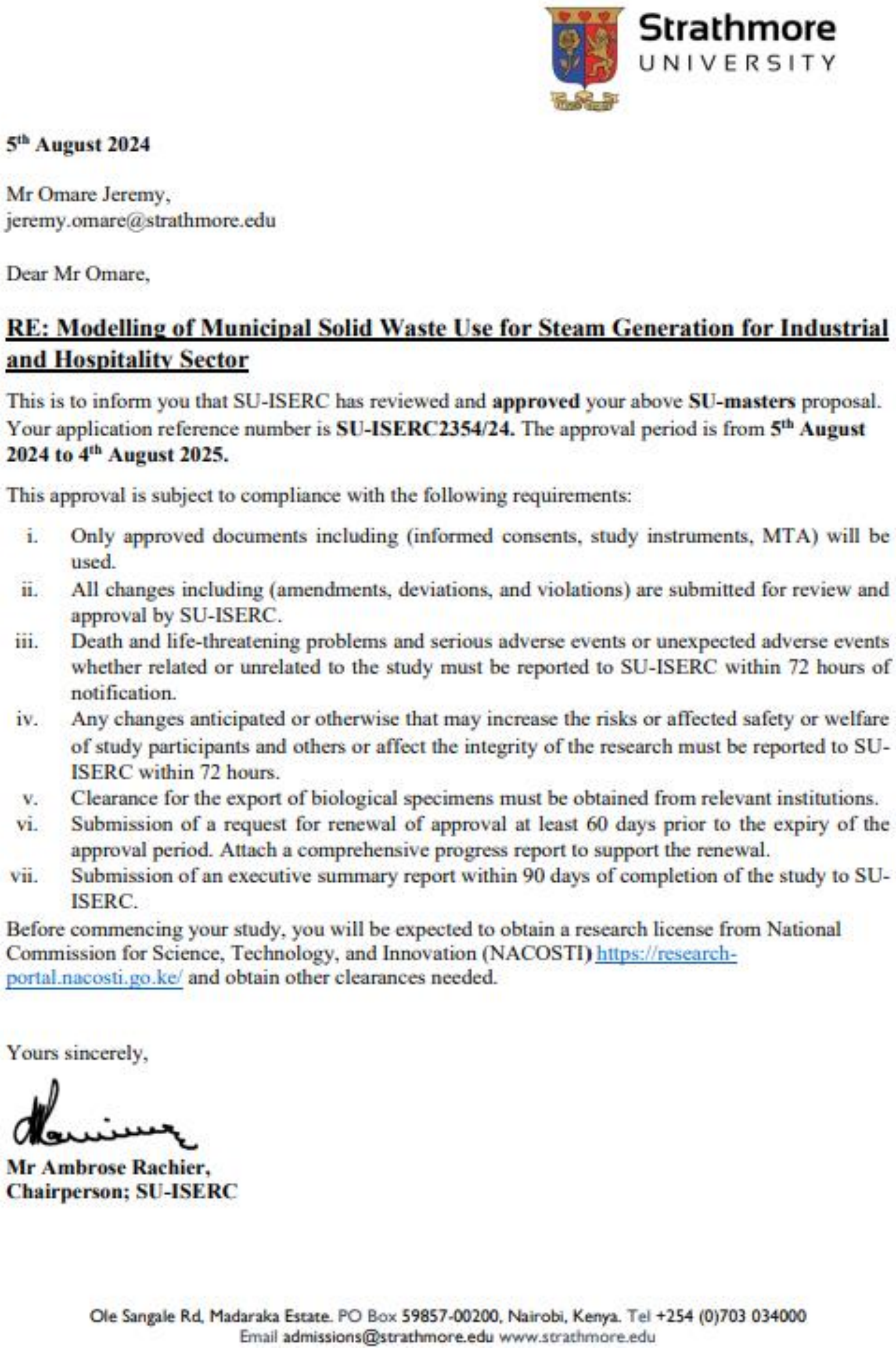
0 Integrity Flags for Review

No suspicious text manipulations found.

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.

Appendix D: Research Ethical Approval



Strathmore
UNIVERSITY

5th August 2024

Mr Omare Jeremy,
jeremy.omare@strathmore.edu

Dear Mr Omare,

RE: Modelling of Municipal Solid Waste Use for Steam Generation for Industrial and Hospitality Sector

This is to inform you that SU-ISERC has reviewed and **approved** your above **SU-masters** proposal. Your application reference number is **SU-ISERC2354/24.** The approval period is from **5th August 2024 to 4th August 2025.**

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by SU-ISERC.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to SU-ISERC within 72 hours of notification.
iv. Any changes anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to SU-ISERC within 72 hours.
v. Clearance for the export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to the expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days of completion of the study to SU-ISERC.

Before commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology, and Innovation (NACOSTI) https://research-portal.nacosti.go.ke/ and obtain other clearances needed.

Yours sincerely,

Mr Ambrose Rachier,
Chairperson; SU-ISERC

Ole Sangale Rd, Madaraka Estate. PO Box 59857-00200, Nairobi, Kenya. Tel +254 (0)703 034000
Email admissions@strathmore.edu www.strathmore.edu