# AN ANALYSIS OF THE ENVIRONMENTAL IMPACTS OF BIOMASS APPLICATION IN HYBRID MICROGRIDS IN SOUTH AFRICA

**By**

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## Declaration

I, Hlonela Gesha, declare that the contents of this dissertation represent my own unaided work, and that the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed                                        Date

## Abstract

In Sub-Saharan Africa (SSA), there are several challenges that hinder development. One of these challenges is access to electricity. There are numerous benefits to having access to reliable electricity. These include less time spent fetching water from rivers and dams, as water purification systems for households could be used in villages; children in villages would be able to spend more time doing their schoolwork and not fetching wood for fire; and automated irrigation systems could be used for villagers to farm and make an income.

Finding alternative ways to generate electricity would enable access to electricity for regions that currently do not have the electricity. This means that large organisations need to find alternative ways of generating electricity, as they have the means to do so.

With the current renewable energy technologies available, there are now more ways in which electricity could be generated. The use of biomass is no exception to this. With constant developments in the renewable energy sector, waste-to-energy (WtE) is proving to be a viable method to generate electricity.

The main aim of this research was to determine if a commercial food retailing organisation could use their food waste for generating electricity for their own use to reduce their demand from the central grid. A way of determining the viability of this type of technology is using a software that simulates renewable energy projects.

In this research, an organisation was contacted for waste data. Systems for two of the stores will be simulated and results will be discussed. The organisation will remain anonymous.

The software used in this research is System Advisor Model (SAM), which was developed by the National Renewable Energy Laboratory (NREL) in the United States.

In the results, three results were discussed. These are the monthly energy, monthly heat rate and the monthly boiler efficiency for each of the stores for Store 1, the annual energy simulated was **138,509 kWh** and **131,677 kWh** for Store 2. Monthly energy averages for each store were **11,542 kWh** for Store 1 and **10,973 kWh** for Store 2, respectively.

There are several opportunities for research based on the findings. These include researching other food sectors in the study; conducting a financial analysis of small-scale WtE systems; constructing a prototype of the system; and using three different softwares to simulate a system for the same project.

# Table of Contents

# LIST OF FIGURES

# LIST OF TABLES

## Glossary

| Key Word | Description |
|---|---|
| Biomass | A renewable energy source that is mainly extracted from waste from agriculture, forestry, energy crops and the biodegradable components of industrial and municipal waste. |
| Biogas | Biogas is a gaseous substance, usually methane and/ or carbon dioxide, produced from the breakdown of organic material in the absence of oxygen. |
| Combined Heat and Power (CHP) | Often termed co-generation, CHP is a process in which both heat and power (electricity) are produced simultaneously in a single process. |
| Food waste | Food waste refers to the decrease in quantity or quality of food due to it being discarded as it no longer serves the intended purpose. |
| Substrate | This often refers to input organic material in a biogas system. |

## Abbreviations

| | |
|---|---|
| NREL | National Renewable Energy Laboratory |
| SAM | System Advisor Model |
| SSA | Sub-Saharan Africa |
| WtE | Waste-to-Energy |

# Chapter 1: Introduction

Energy security and low electrification rates in SSA are both issues that have been faced by the continent. With developments in the renewable energy sector, there are many technologies that can be used to generate electricity to reduce high demand from the central electricity grid and electrify those areas that are currently without electricity.

With the progression of time, land resources to use as landfills are becoming depleted. This means that alternatives for transferring waste from households and businesses need to be explored. WtE is a good example of how waste can be used for other purposes to ensure that not only the environment is protected, but also electricity is provided for different uses.

This dissertation focuses on exploring the applicability of WtE technology for energy generation in the commercial food retailing sector. A computer software, SAM, will be used in this research to determine how much energy would be generated from the food waste accumulated in a fruit and vegetable retailer in South Africa.

It should be noted that data from two stores from the organisation's list will be investigated in this research. Results will be separated per store. Both these stores are in the Western Cape, South Africa, and they are both relatively similar in size.

In this chapter, a background to the research is provided; the objectives and research questions are identified; the methodology is defined; and the structure of the dissertation is briefly explained.

## 1.1. Statement of the Research Problem

The commercial food retailing sector produces a large amount of waste. As food waste is one of the classes of biomass, this makes it a good source for electricity production in a biogas system de Lange & Nahman, 2015). Not only is finding alternative use for this type of waste good for electricity production to reduce demand on the electricity grid, it is a good way of minimising waste in landfills.

## 1.2. Project Background

As it will be further explained in the Literature Review, the lack of electrification in many African countries has been, and continues to be a great challenge. There are several benefits linked to having access to electricity (European Suppliers of Waste to Energy Technology, 2012). These include more study time for school children, resulting to increased performance at school; automated irrigation for subsistence farmers, resulting to more time to perform other tasks; and access to potable water, resulting to women spending less time fetching water from rivers.

The commercial food retailing sector produces large amounts of food waste daily. One of South Africa's largest food retailing stores has been contacted for data collection for this research. For confidentiality, the retailer has asked that the data be kept confidential. Only the findings will be presented in this research.

With evolving technologies used to generate electricity, food waste can be used as a power source on a smaller scale, compared to the capacity required to generate power for a central electricity grid (Deltaway Energy , 2017). This food waste can be used in a biogas system where gas is produced to generate electricity.

Landfills in South Africa are filling up at an alarming rate, and land resources for storing waste are running out. Finding an alternative way of using food waste will result in a reduction, although by a small percentage, in waste dropped off in landfill sites. This will have a ripple effect, as this will also result in new markets opening in South Africa.

This research attempted to investigate how much food waste from a commercial food retailer is required to power a WtE system in South Africa.

## 1.3. Research Question

This part of the research will list the research questions that will be addressed in this dissertation.

1. Can food waste from a commercial food retailer be used to generate biogas for application in a WtE system?
    a. How much food waste from a commercial food retailer would be required for application in a WtE?

## 1.4. Research Objectives

The main objectives as to why this research will be carried will be identified and listed in this section.

1. To understand the feasibility of using food waste for electricity generation.
    a. To understand how much food waste can be used to generate electricity for a WtE system.

## 1.5. Research Design and Methodology

There is opportunity to generate energy using waste, resulting in a reduction in the amount of waste that goes to landfills. This research aims to investigate, through software modelling and design, the amount of waste required to generate biogas in an anaerobic digestion system to power a WtE system.

The company, from which data will be collected, has several stores in South Africa. It should be noted that two of their stores will be used as case studies to determine the viability of the proposed project. The selected stores are two of the organisation's most successful stores in the Western Cape.

The research methodology is divided into two parts. These parts will be discussed in the sub-section below.

### 1.5.1. Research Design

For data collection for this research, monthly waste production from the food retailer stores in the Western Cape will be analysed over a period of 12 months (March 2016 to April 2017). This is to provide a representative figure for waste generated monthly by other equivalent commercial food retailers in the country. The selected retailer sells fruit and vegetables; meat; and non-perishable products. The waste in question will be solely organic waste, such as all fruits, all vegetables and different kinds of meat, that can be used in a biogas system, which would ideally be used to power a CHP system for the organisation's head office in the province.

#### 1.5.1.1. Data Collection

The first part is to collect and analyse monthly waste generation data from the selected store over a period of one year. This data will be used to determine the monthly energy production from the proposed biogas system.

It should be noted that data will not be physically collected from the store. The reason for this is that the organisation has a system in place where waste is collected, recorded and can be accessed by various stakeholders.

An external company is contracted by the food retailing organisation to manage waste collection at the various stores in the Western Cape. The external company measures waste daily during collection.

Once the waste data has been collected, it is captured on a system which can be easily accessed by the organisation and other stakeholders.

A platform in the form of a website is used, where the organisation can log in and analyse the data. The website allows the user to custom search the data per store and on specific dates. This data can be extracted into a Microsoft Excel spreadsheet, where it can be easily analysed and manipulated. The software also generates different kinds of graphs for the user to easily interpret the data.

### 1.5.1.2. Software Modelling and Simulation

The second part of the research methodology will be to use renewable energy modelling and simulation software to determine the amount of energy that would be generated for the system with the amount of waste generated on an annual basis. The software that will be used is System Advisor Model (SAM), which was developed by the National Renewable Energy Laboratory (NREL).

The NREL is a government-owned organisation in the United States that specialises in research, development, commercialisation and deployment of renewable energy and energy efficiency technologies (U.S Department of Energy, 2016).

The System Advisor Model (SAM) software is a product of the NREL that allows users to model, design and simulate a renewable energy system or technology. This includes solar, wind and bioenergy systems. This research focuses on modelling bioenergy output from the system.

Outputs of the SAM software include the following:

- Modelling renewable energy systems
- Energy generated from the various energy sources
- Results extraction in the form of Microsoft Excel documents, graphs and tables

Upon opening the software, the user is required to select the type of technology to be modelled. These include solder PV, concentrated solar power plant, wind farm, biomass combustion and solar water heating. Once the technology has been selected, the user is required to select a financial model for the system.

The following step is to select the location where the system will be placed together with the climatic conditions. The software provides climatic conditions for the various cities listed in the software. It should be notes that South Africa is not an option in the software. For this reason, a city with similar climatic conditions has been selected. Cape Town has a Mediterranean-style climate. A city with a similar climate in the United States is Los Angeles (Wikipedia, 2017).

Once the location has been selected, the biomass data is typed in. This step requires the organic waste data for a full year. This step determines the capacity of the system (in kW). For this research, this data has been collected and provided by the food retailing organisation.

System Specification is one of the most important steps, as it allows the user to select the type of combustion system to be used for power generation. This research investigates the use of the use of the grate stoker furnace. This step also allows the user to select the number of boilers used and the temperature at which steam will be produced.

The software allows the user to provide gas emission information. This information is used to determine the carbon dioxide emissions from the transportation of the biomass from the source to the location of the plant.

Once all the important information and variables have been provided, the user simulates the system. Results tables and graphs are produced, and the user can easily analyse the information. The results can be extracted into a Microsoft Excel document for better analysis.

Since South Africa is not listed as one of the countries in the SAM software, the following consideration had to be taken:

- The climatic conditions of Los Angeles, United States, have been used as those of Cape Town.

The software modelling and simulation will assist in determining the physical size of the biogas system, considering all the specifications computed in the software.

## 1.6. Delineation of the Research

Boundaries to the research include the following:

1. The types of food waste that will be analysed for this research are fruits, vegetables and meat products.
2. Only the food retailing sector will be considered in this research.

## 1.7. Thesis Outline

Chapter 2 of this research provides a literature review that provides an explanation of food waste in the global food retail sector, with a detailed explanation of food waste in the fruit and vegetable retail sector. Chapter 2 focuses further on food waste in South Africa and what the trends have been the past few years. Lastly, chapter 2 provides a detailed explanation of what WtE is and the various technologies used in the process.

Chapter 3 provides detailed steps taken during the software modelling stage of the research, using the (SAM). Data from two food retailing stores is used in this software modelling. This is to ensure that the reader can duplicate the process, should they be interested in modelling a WtE project.

Chapter 4 provides results from the software modelling of the two stores used. These results are in the form of graphs and tables. These results are also discussed in this chapter.

Lastly, chapter 5 discusses the key findings from the research and provides a conclusion to this research.

## 1.8. Summary

Energy security is one of the many challenges faced by many Sub-Saharan African countries (Eberhard, *et al.*, 2017) . This limits the rate of development in these countries. There are several ways in which the challenge of energy security can be addressed. This includes energy efficiency and renewable energy implementation across the different economic sectors. The commercial sector is one of the sectors with large energy needs.

This means that alternatives are required to reduce energy consumption in the commercial sector. Provided that waste generation is one the major issues faced in the commercial sector, particularly the food retailing sector, there is an opportunity to convert waste to energy, using technologies or processes such as anaerobic digestion.

There are different types of substrates that can be used in biogas systems (Hanssen, *et al*., 2015). These include cattle manure (in liquid or solid form), pig manure (in liquid or solid form), grass cuttings, corn straw and food waste. This research focuses on solely food waste. A commercial food retailer in the Western Cape has been contacted for data.

The amount of energy generated in this process can be modelled using a few energy modelling and design software. The software used in this research is System Advisor Modelling. This software allows the user to provide input data and the software calculates the amount of energy that would be produced, in relation to the input data.

The software also provides the user with tables and graphs that illustrate the system results in an easy-to-read format.

## Chapter 2: The Use of Food Waste for Electricity Generation

The concern of growing world populations is becoming more prevalent as the time progresses. There are a number issues associated with accelerated population growth. These include the issue of land masses being cleared for larger food production, resulting in increased greenhouse gas emission, due to reduced trees in forests for carbon dioxide; and the issue of increased volumes of waste in landfills (Ravindran & Jaiswal, 2016).

As opposed to looking at food waste as a challenge, it is greatly encouraged that it be seen as an opportunity for the creation of new markets. There are a number of new technologies being deveoped with the intention of reducing waste to lanfills. These technologies are used in the following sectors (Ravindran & Jaiswal, 2016):

- Biorefinary industry
- Chemical industry
- Renewable energy sector

Food waste in the renewable energy sector is a valuable resource that often does not receive the attention it needs. Through anaerobic digestion, among other methods, electricity can be generated using food waste. In an anaerobic digestor, enzymes convert the organic waste into methane gas. The residue from this process is used as fertilizer in the agricultural sector for crop production (Environmental Protection Agency, 2016). This method will be looked at in greater detail further in this research.

As the commercial food sector is one of the main contributors to the accumulation of waste to landfills, the three sectors within the commercial food retail sector that will be explored in this research are the commercial fruit and vegetable retail sector.

The main aim of this research is to determine the applicability of using waste from the above-mentioned sectors to generate energy for their own use; and what that energy would be used for.

In order to determine the exact amount of energy that would be generated (in an ideal situation) from the waste, a software will be used. In this software, the annual waste generated by each of the sector will be inputed and the results will be analysed. The software that will be used for this research is System Advisor Model (SAM).

A brief history of solar photovoltaic energyy will be discussed in relation to biomass.

## 2.1. A Brief History of Solar Photovoltaic (PV) Technology

The use of the sun to generate energy is not a new concept. The use of the sun for energy generation started in the 7th century B.C., where a magnifying glass was used to concentrate the sun's rays to start a fire (U. S. Department of Energy: Energy Efficiency and Renewable Energy, 2018). Through the years, the use of the sun for energy generation has evolved tremendously. From it being used for cooking by scientist Horace de Saussure in 1767, to being used for the first time to generate electricity through the photovoltaic (PV) effect in 1893 by scientist Edmond Becquerel (Hoang, 2017).

The use of solar PV for generating electricity has developed at an exponential rate over past few decades and centuries. A number of technologies have been explored, developed and tested to further improve this technology. Ribbon silicon, thin-film technologies, mutlijunction technologies and transparent luminescent concentrators are some examples of these different technologies (Hoang, 2017).

There are a number of ways in which electricity can be generated using solar PV. These include rooftop solar PV, concentrated solar PV and ground-mounted solar PV plants (National Energy Education Development Project, 2017). These methods make it easier to generate electricity using this renewable energy technology.

With the progression of time, the components required for solar PV plants has evolved and become more efficient. The main components of a solar PV system are the solar panels; inverters; smart, bi-directional meters, to name a few. These components are important for a fully functional solar PV system (Hoang, 2017).

These developments in the solar energy sector have led to the development of othe renewable energy technologies such as wind, hydro and biomass.

With that brief history of solar PV, the next section of this research will focus on the use of biomass to generate electricity. It should be noted that the sector used to determine the applicability of this research is the commercial food retailing sector. The reason for the use of this sector is that there is great potential to reduce waste taken to landfills for processing.

## 2.2. Food Waste in the Food Sector

As previously mentioned, the food retail sector is one of the main contributors to the large quantities of waste that are sent to landfills. This is a growing concern, as land resources for this purpose are limited for the creation of more landfills. This section of the research discusses waste accumulation in the fruit and vegetable retail sector.

### 2.1.1. Fruit and Vegetable Retail Sector

Food waste from the fruit and vegetable retail sector can be used for several commercially viable products, using various methods and technologies. In Figure 1, an illustration of these products is provided.

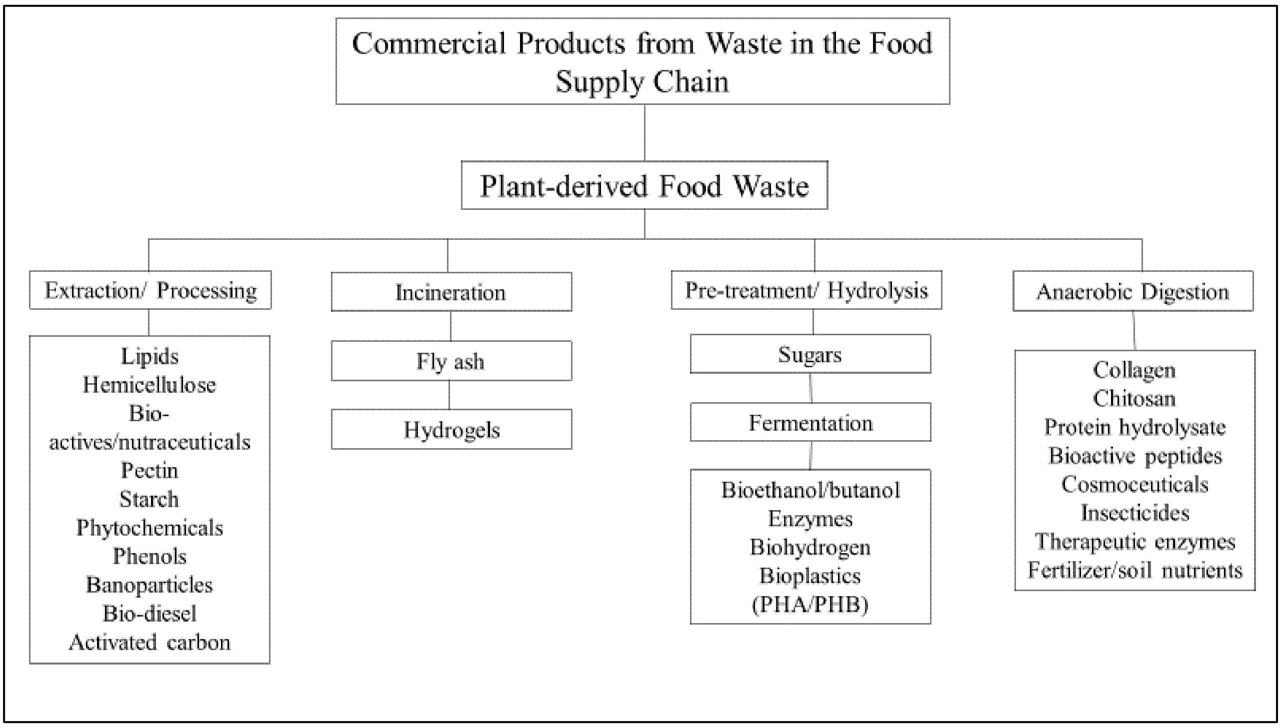


*Figure 1: Commercial products that can be extracted from food waste in the food supply chain (Ravindran & Jaiswal, 2016)*

Looking at figure 1, it is evident that there are several products that can be derived from food waste, particularly looking at plant-derived food waste.

Among the many issues associated with the non-treatment of food waste, it is important to take into serious consideration the environmental impacts and consequences. These consequences are two-fold; on the one hand, food waste can result in the formation of leachate, which may seep into, and contaminate, underground water supplies; on the other hand, energy used for the production, transportation of the wasted food resulted in the use of non-renewable energy resources, that have a negative impact on the environment.

In a study carried out by Hanssen, *et al*. (2015), it was indicated that in Norway, the composition of three different types of meals, as illustrated in the Table 1.

*Table 1: Composition of Three Different Types of Meals in Norway (Hanssen, et al., 2015).*

| **Composition of Three Different types of meals in Norway** | | | |
|---|---|---|---|
| | **Ready-to-Eat Meals (%)** | **Semi-Prepared Meals (%)** | **Home-made Meals (%)** |
| Meat | 44.9 | 38.5 | 43.8 |
| Vegetables (Peas) | 20.5 | 17.5 | 19.9 |
| Vegetables (Potatoes) | 34.6 | 29.7 | 33.7 |
| **TOTAL** | **100** | **85.7** | **97.4** |

As indicated in Table 1, vegetables are a large part of the different types of meals that are consumed by people. As indicated in section 2.1.3, food waste in the food industry is very common, especially in developing countries. This means that the food that is not consumed is sent to landfills. This is an opportunity to recycle and reuse these waste products, particularly fruit and vegetables, for the products indicated in figure 1.

Organic material such as food waste is a useful source for waste-to-energy (WtE) due to the anaerobic digestion that occurs in the process. Not only does anaerobic digestion in the WtE process produce energy, it also produces sludge as a by-product. The sludge can be used in agriculture as a fertilizer for crop production.

Anaerobic digestion is one method/ technology that will be looked at in greater detail. In other processes within anaerobic digestion, fuels and energy can be derived, with sludge as a by-product.

## 2.2. Food Waste in South Africa

The commercial sector is one of the sectors that generate large amounts of waste. These wastes include organic, solid, hazardous and recyclable wastes respectively. For this research, organic waste will be focused on in greater detail.

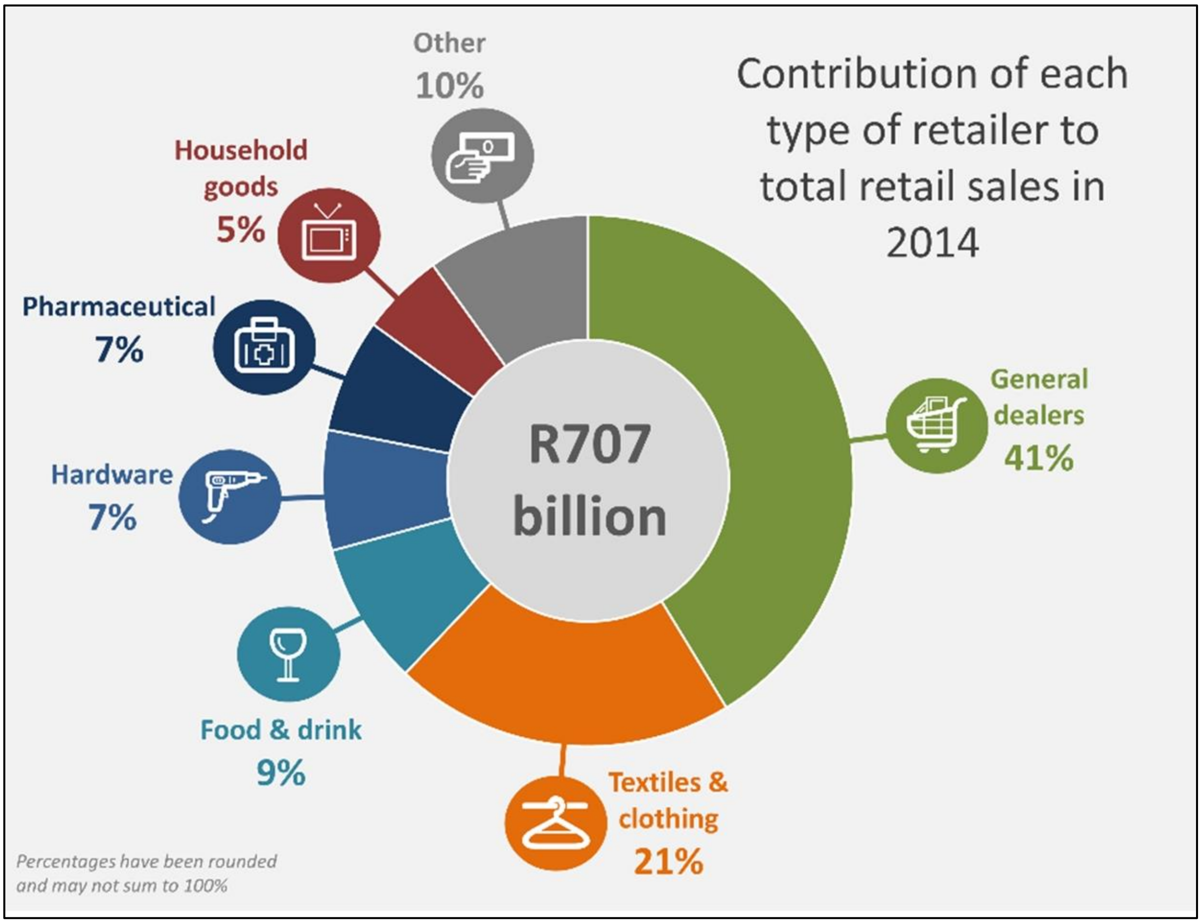


*Figure 2: An illustration of the contribution of all retail types in the South African market in 2014 (Statistics South Africa, 2015).*

Figure 2 is a graphical illustration of the contribution of the different retail sectors in South Africa for the year 2014. The food and drink sector contributed 9% to the total sales in this year, which means that out of the seven retail sectors, it was the fourth leading retail sector.

As the food and drink sector was one of the major contributors to overall sales in the country, it could be assumed that large volumes of waste were generated in the sector.

The agricultural sector is one of the key sectors in Souh Africa's economy (The South African Guide, 2016). It has been said that the more an economy grows, the more issues arise from that growth. For example, energy requirements increase as a result of this growth. Another issue that is often overlooked is that of waste generation. With current developments and on-going research, there are opportunities to convert waste into energy.

Taking a closer look at the agricultural sector in South Africa, Urban Earth (2012) indicated that South Africa generated approximately 9 million tonnes of food waste in the year 2012; 26% of which is from agricultural production. Figure 3 below provides an illustration of this.


*Figure 3: A breakdown of the different sources of food waste in South Africa in the year 2012 (Urban Earth, 2012).*

Looking at figure 3, food waste is a problem in South Africa. This is an opportunity to create new markets in the country and boost the bioenergy sector using food waste as a source of energy.

The 2012 South African National Waste Information Baseline Report by the Department of Environmental Affairs stated that organic waste, which comprised garden and food waste, accounted for 13% of the general waste in South Africa. Approximately 65% of this organic waste was transferred to landfills (de Lange & Nahman, 2015). Taking into account the current trends in the development of WtE technologies, there are great opportunities for converting waste into usable energy.

As the Commercial sector as a whole accounts for 11.4% in the country, the WtE process could suppliment the sector's energy needs and reduce demand on the electricity grid (Department of Energy, 2014).

## 2.3. Waste-to-Energy (WtE)

With the progression of time, technologies used for electricity generation are constantly changing, allowing for more advanced technologies to be developed and, eventually, used to generate electricity. WtE is no exception to this. There are many benefits linked to the use of WtE techniques. These include reduced greenhouse gas emissions; less land being used up for landfills; and a closed production loop, especially in the retail sector (Wang, *et al.*, 2017).

The image in Figure 4 provides a detailed illustration of the WtE process, from the waste input stage through to the end stage, where energy is produced, together with other by-products (Abad, *et al.*, 2015). The energy produced can be in two forms; it can be converted directly into electricity or into a biogas. The biogas can later be used to generate electricity in a gas-operated system. The type of energy produced is highly dependent on the type of technology used for WtE.

It should be noted that this is not the only method used in a WtE process/ plant. There are numerous other methods. This one has been used to provide the reader with the general idea of what WtE entails. Other technologies will be discussed later in this chapter.

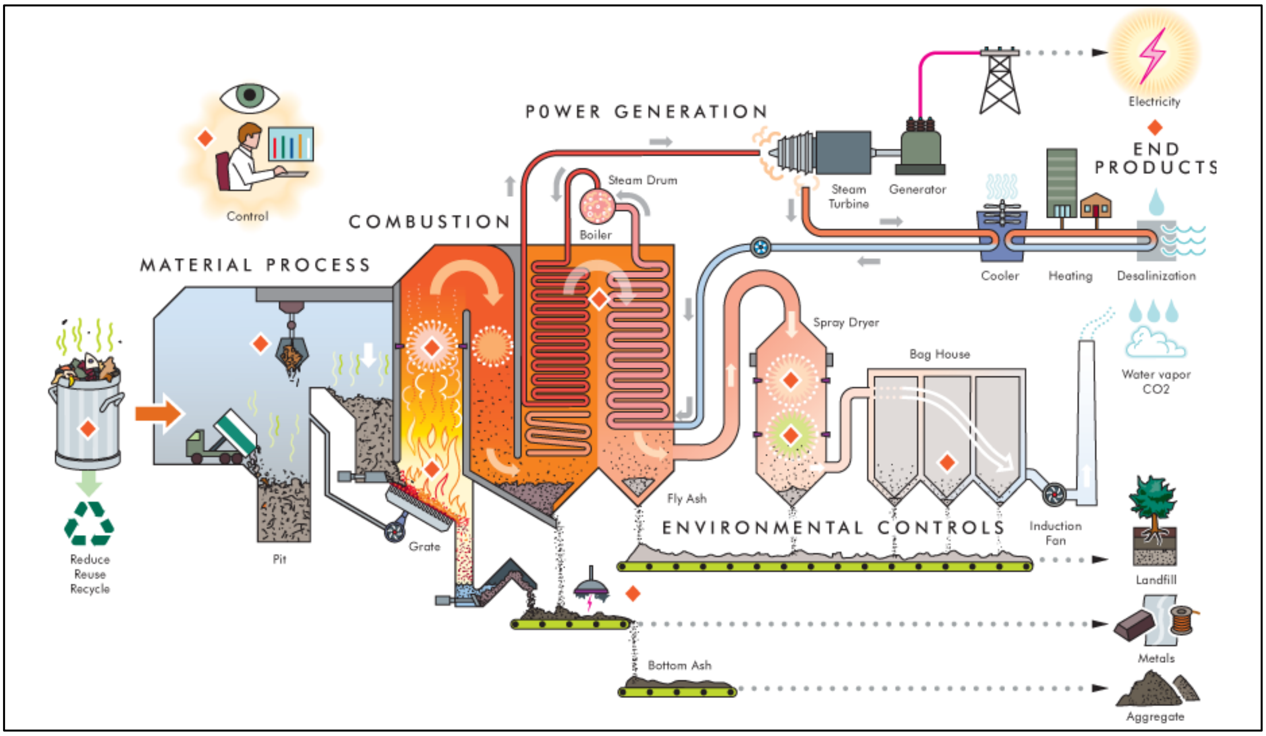


*Figure 4: A detailed graphical illustration of the waste-to energy process (Deltaway Energy , 2017).*

### 2.3.1. Different Stages of WtE

The different stages of WtE under ideal conditions (European Suppliers of Waste to Energy Technology, 2012) are as detailed hereunder:

- **Step 1 – Waste Input and Combustion**
    - Waste that was initially transferred to landfill sites is redirected to a WtE facility, where waste is transported by the grate and is burned. Material that cannot be burned is transferred to the bottom of the grate, where it can be recovered and used as a raw material in other processes.

- **Step 2 – Energy Recovery**
    - In this step, boilers are used to recover a majority of the energy contained in the waste, approximately 80% of the energy. Once this is complete, the energy is then used to generate steam.

- **Step 3 – Flue Gas Cleansing**
    - This step ensures that any of the pollutants contained in the waste and in the gas generated are removed. This is to ensure that the gas can be used without having pollutants released into the environment.

- **Step 4 – Energy Utilisation**
    - Once all the necessary steps have been taken, the energy generated can be used. As indicated earlier, the energy can be in the form of electricity or as a biogas.

One of the most important steps when it comes to WtE facilities is the monitoring and control of the system. Trained individuals operate the facility to ensure that each of the plant components are fully operational, specifically the air stream that goes into the stacks. This is to ensure that the air quality standards are maintained (Deltaway Energy , 2017).

According to Deltaway Energy (2017), transferring waste from landfills to WtE facilities has the potential to reduce the amount of waste in landfills by 90%. This is a significant figure, taking into account the fact that globally, land resources to accommodate lanfills are being depleted.

With the ever-evolving technologies, computer software, and energy modeling techniques, designing and simulating these WtE plants before they are built has become an important step in determining if these plants are worth the financial investments.

### 2.3.2. Technology Used in WtE Plants

With the progression of time, the technology used in WtE plants has evolved to become more efficient than their predecessors. In this section of the research, three technology types will be discussed. These technologies are listed below.

#### 2.3.2.1 Direct combustion:

This type of technology comprises of two types of techniques; namely mass burning and Refuse-derived Fuel (RDF). Mass burn entails that the raw waste material is burned/ incinerated as it is, ensuring that all the combustible material is burned, and the non-combustible material remains. In this process, the heat is used to generate steam, thus generating electricity. Alternatively, the gas from this process can be captured and used in other applications. In the RDF technique, recyclable material is removed from the raw waste that enters the plant, ensuring that the remaining material is only combustible material that can be used to generate steam or gas. See figure 16 in the Appendices for a detailed image of these two processes (Stringfellow , 2014).

#### 2.3.2.2 Pyrolysis

Pyrolysis works in extremely high temperatures. In this technology/ process, organic material is decomposed at extremely high temperatures (approximately between 650°C and 1200°C) without oxygen as a by-product. The gas produced by this technology can be converted into liquid products such as biodiesel and chemical adhesives (Stringfellow , 2014). An example of a pyrolysis plant is the Toyohashi City, Japan, which processes 400 tonnes of Municipal Solid Waste (MSW) per day. See figure 17 in the Appendices.

#### 2.3.2.3 Conventional Gasification

Gasification, similar to incineration, involves the burning of MSW to produce a synthetic gas and ash as a by-product. This synthetic gas can be used in several applications, such as the generation of electricity to produce steam or as a chemical feedstock in other processes (Tan, 2013). Gasification happens at temperatures between 760°C - 1500°C. An example of such a plant is the Kawaguchi, Japan, which process 400 tonnes of MSW per day. Figure 18 in the annexure illustrates a detailed image of the gasification process.

# CHAPTER 3: ENERGY SYSTEM DEVELOPMENT AND MODELLING

## 3.1. Introduction

The use of energy modelling software is useful in more several ways for Energy Project Managers, System Developers and Decision Makers in energy development projects. Energy modelling software assist the users by simulating the approximate capacity of energy projects, the costs involved, and the lifespan of the projects.

Software Advisor Model (SAM) has been used for this research to model a small-scale waste-to-energy facility for a food retailing organisation in South Africa. Annual waste data, particularly food waste, was analysed and inputted into the software to determine the amount of energy that would be produced with the food waste. This is to determine the applicability of deferring waste from landfills to these waste-to-energy facilities for the food retailing sector.

Before inputting the waste data into the software, a few variables had to be selected. These variables include the location of the project and climatic conditions; feedstock information; plant specifications; and emissions information. Provided that this information was satisfactory to the user, the simulation was run, and the estimated nameplate capacity of the simulated system was determined.

The organisation on which this research is based is a South African food retailing organisation that sells fruits, vegetables, meat and non-perishable products.

It should be noted that SAM does not include any South African cities where the location had to be selected. For this reason, a city (Los Angeles) with similar climatic conditions to Cape Town was selected.

Results from each of the steps taken in the simulation will be discussed in this chapter. Detailed system results will be discussed in Chapter 4.

## 3.2. Software Description: System Advisor Model

The software that will be used is System Advisor Model (SAM), which was developed by the National Renewable Energy Laboratory (NREL). It should be noted that most of the information in this sub-chapter was obtained from a publication on the SAM by the NREL, published in February 2014.

The National Renewable Energy Laboratory is a government-owned organisation in the United States that specialises in research, development, commercialisation and deployment of renewable energy and energy efficiency technologies (U.S Department of Energy, 2016).

The System Advisor Model (SAM) software is a product of the NREL that allows users to model, design and simulate a renewable energy system or technology. This includes solar, wind and bioenergy systems. This research is focused on modelling bioenergy output from the system.

Out of the many capabilities of the SAM software, below are a few of these:

- Modelling renewable energy systems
- Financial analyses
- Energy generated from the various energy sources
- Results extraction in the form of Microsoft Excel documents, graphs and tables

The use of SAM is not only limited to Engineers and Renewable Energy Specialists. Other users include Project Managers, financial and policy analysts, technology developers and researchers. The software is user friendly, once the user become familiar with the functions in the software.

The first step when using SAM is to select the type of technology that will be simulated and modelled with the appropriate dataset. Depending on the purpose of the project being simulated, there are additional options that the user has to choose from to have detailed project simulation results. These are for the size of the project, meaning if the project is commercial, industrial, utility-scale, or if the project is a small-scale single unit project (See figure 5).

It should be noted that the figures illustrating how the software is used are not the actual figures for this research. They are used to merely illustrate the kind of data that is required for software simulation on SAM. The actual input data and results for the research will be discussed below.

As it would be difficult to determine the size of a small WtE plant, the amount of waste required for the plant and the costs involved in investing in such a plant before implementing it, the use of computer software was very useful for this research. With the aforementioned capabilities and functionalities of the SAM used in this research, the sizing of a WtE plant became less challenging.

For the biomass component of the system, not much input data was required. Taking into account the fact that the financial modelling part of the system was not done, the only required data was the amount of waste generated over a year, which translates into the amount of electricity generated over a period of a year.

Looking at figure 5 below, there are various financial models that can be explored when using this software. For this research, the financial modelling component was not explored. The reason for this is to reduce the complexity of this research. It has been recommended that to supplement this research and determine the feasibility of this simulated plant, a detailed financial model should be developed. This would further inform decision within the commercial food retailing sector on whether or not to explore this option for waste-to-landfill reduction.

**Step 1:**

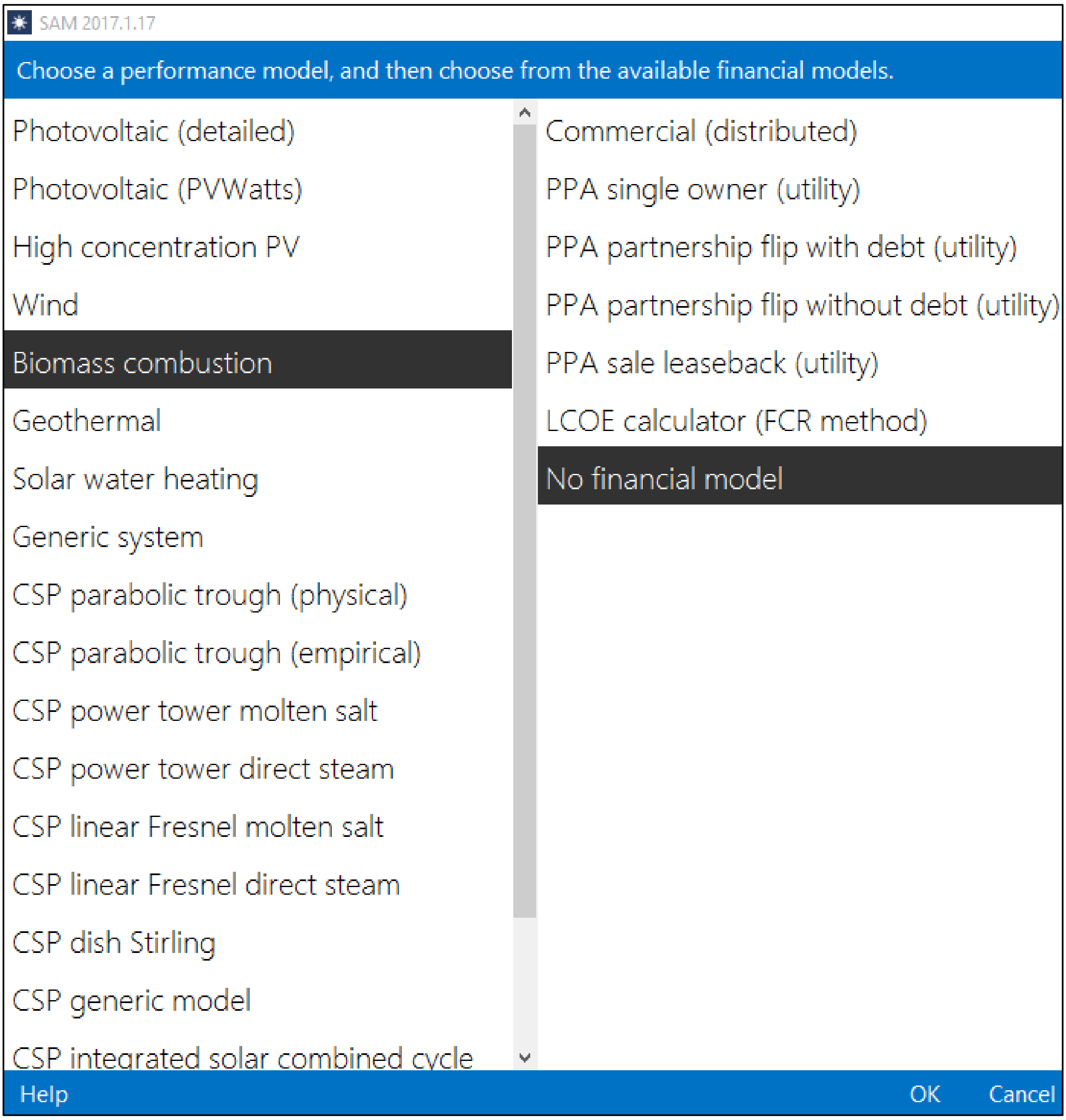


*Figure 5: An image illustrating the various projects that can be simulated in SAM*

The following step is to select the location where the system will be, together with the climatic conditions. The software provides climatic conditions for the various cities listed in the software. As this software was developed in the United States of America, most of the cities in the weather profile and ambient conditions step are US cities (See figure 6).

**Step 2:**

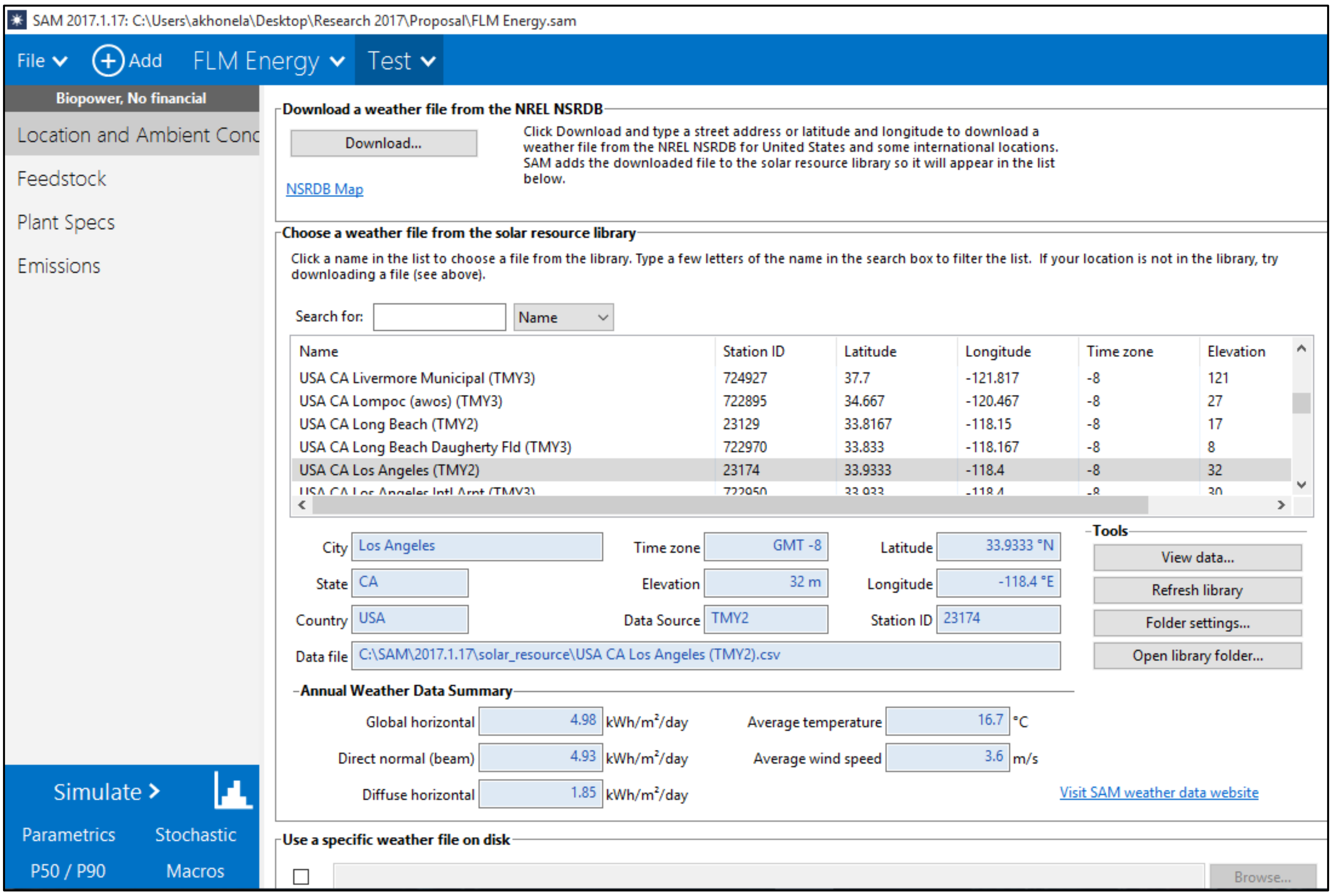


*Figure 6: An image illustrating the section of location of the project and ambient conditions on SAM*

Once the location and the preferred ambient conditions have been selected, the feedstock amounts must be computed into the software. Once the location has been selected, the next vital step is to compute the feedstock information for the system. Figures 7 and 8 illustrate this step.

**Step 3:**

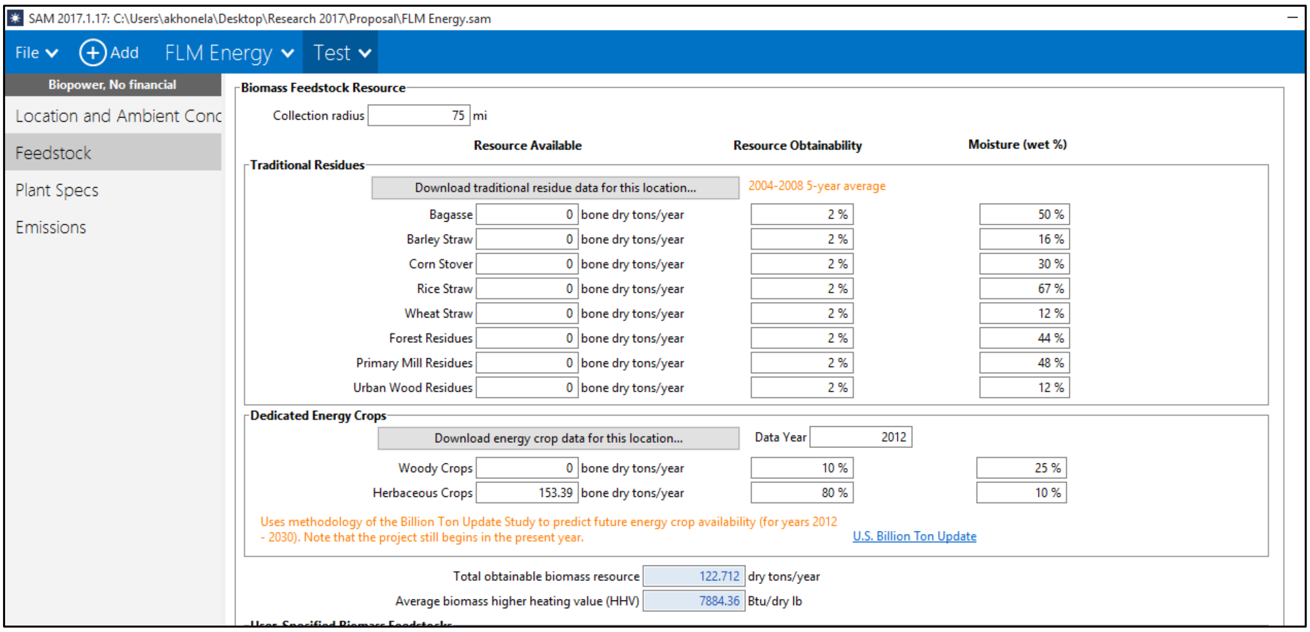


*Figure 7: An image illustrating the platform on which the software user computes feedstock for the system simulation on SAM.*

For the system to simulate how much electricity would be produced, in ideal conditions, using biomass, the user is required to compute the amount of biomass produced each year. This requires the data to be collected for a full year for the system to simulate realistic figures. This section/ step breaks down the biomass into different categories. These categories include the following:

- **Traditional biomass:**
  - Bagasse
  - Barley straw
  - Corn stover
  - Rice straw
  - Wheat straw
  - Forest residue
  - Mill residue
  - Wood residue
- **Dedicated energy crops**
  - Woody crops
  - Herbaceous crops

Among the results simulated by the software, the total obtainable biomass for the year is estimated (in dry tonnes/ year). This figure is based on the moisture content of the feedstock. The higher the moisture content, the higher the total obtainable biomass figure.

Should the user have additional biomass that is not listed above, then they can add the additional data (See figure 8).

**Step 4:**

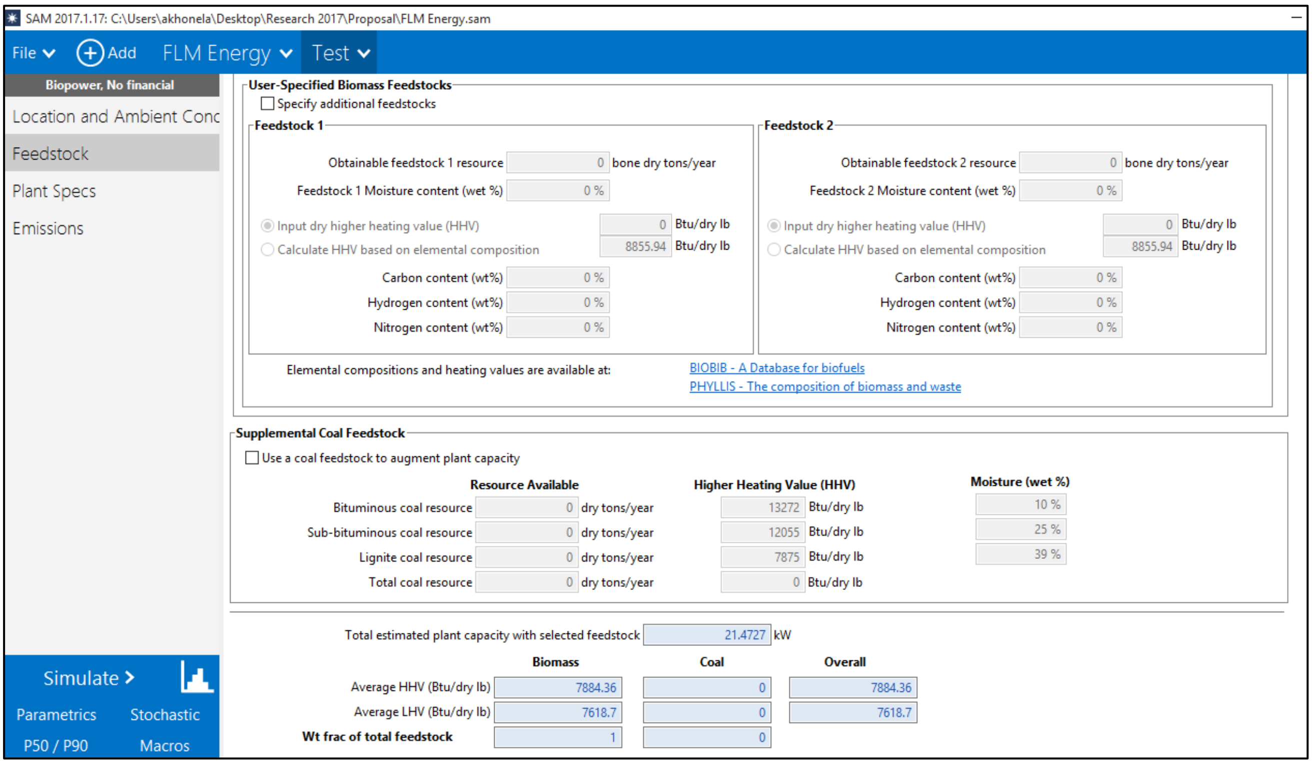


*Figure 8: An illustration of the space provided by the software for the user to add extra information for the system simulation*

Once the feedstock information has been computed, the software estimates the capacity of the system (in kW) (See figure 9).

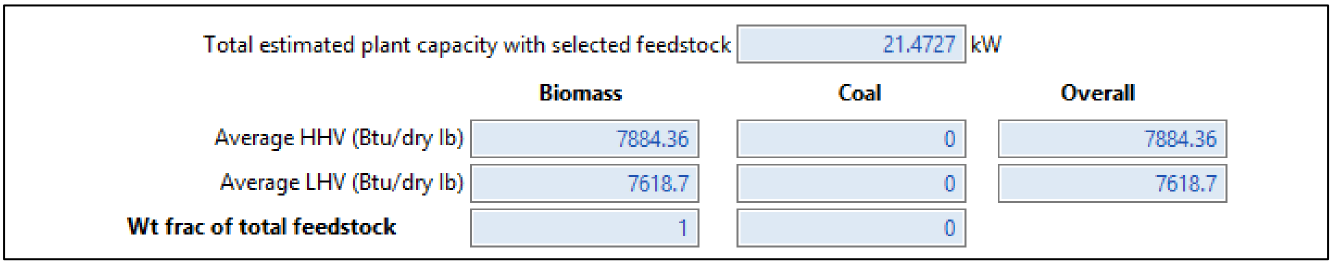


*Figure 9: An illustration of the simulated capacity of the system, based on the computed feedstock.*

Another important step when working with SAM is the selection of the plant specs. It is important that the user is familiar with the different combustion systems used in the software simulation before selecting which combustion system to use. The different systems give different results for the nameplate capacity of the simulated software.

Below is an image illustrating the different information provided by the software, SAM, about the boilers.

**Step 5:**

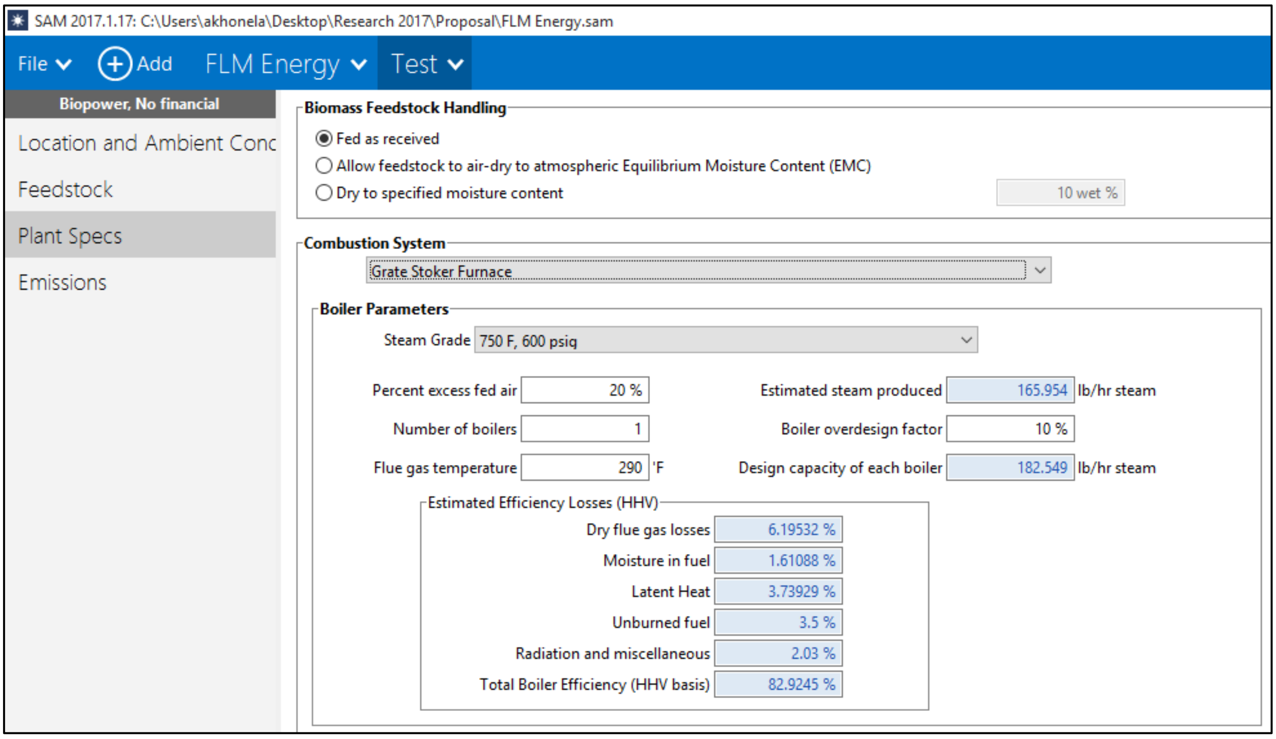


*Figure 10: An image with the different boiler information shown on SAM*

**Step 6:**

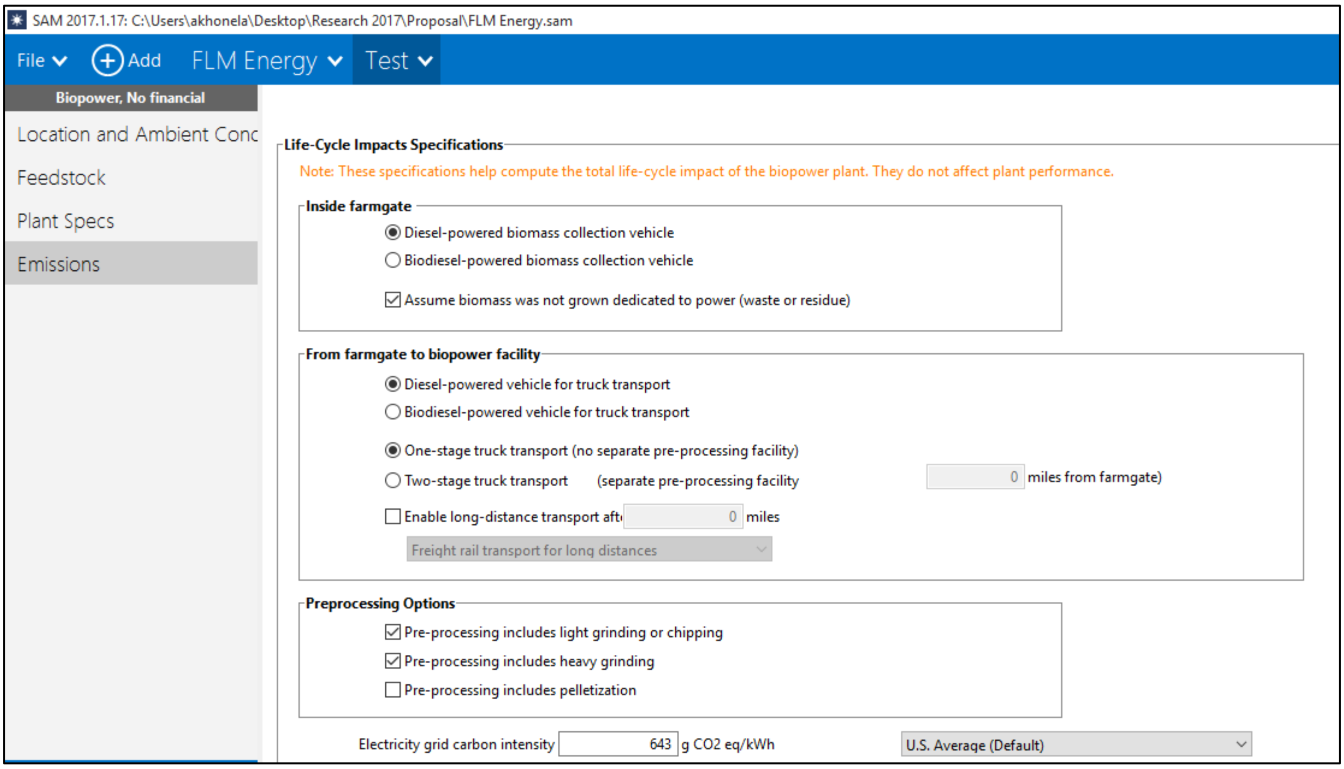


*Figure 11: An image illustrating the life cycle impact specifications of the plant being designed*

It is important to note that this information does not affect plant performance. It is merely an indication of variables such as the type of fuel used to transport the biomass from site to the plant; and the type of processing options available for the user.

Once all the important information and variables have been provided, the user simulates the system. Results tables and graphs are produced, and the user can easily analyse the information. The results can be extracted into a Microsoft Excel document for better analysis.

Considering that South Africa is not listed as one of the countries in the SAM software, the following considerations had to be taken:

- The climatic conditions of Los Angeles, United States have been used as those of Cape Town.

The software modelling and simulation will assist in determining the physical size of the biogas system, considering all the specifications computed in the software.

## 3.3. Input Data and System Results

One of the largest fruit and vegetable retailing organisations in South Africa was contacted for data for the energy modelling component of the research. For confidentiality purposes, the name of the organisation shall not be mentioned.

In this case study, we shall determine the effectiveness of small waste-to-energy projects in the food sector. The main aim of the case study was to investigate whether diverting waste from landfills to a waste-to-energy facility could be used to generate their own electricity to be used for either lighting, air conditioning or to power certain equipment at their stores in the food sector.

This investigation is to determine the possibility of waste and carbon footprint reduction in the food supply chain, particularly the food retail sector.

Looking at the size of the food retailing organisation this research focused on, there are several stores in the country. To avoid complexity in the study, one store in the Western Cape was focused on. The store is in the Northern suburbs in the City of Cape Town region. The store sells a range of food products, including fruit and vegetables, meat, non-perishable food, and sea food.

The tables 2 and 3 illustrate the types of waste that the organisation generates and their quantities on an annual basis. It should be noted that the waste is divided into two groups, waste to recycling and waste to landfill.

The food waste in Table 2 and Table 3 (highlighted in yellow) is the total food waste generated by two of the stores in the Western Cape over a year, respectively. The organisation is in partnership with a waste collection company that records the amount of waste collected every month using an automated system. This system the allows the user to extract the data onto Microsoft Excel, making it easier to manipulate with the data.

*Table 2: A table illustrating the amount of waste generated in one year by the organization this research is based on for store 1.*

| Annual Waste Generated | |
|---|---|
| **Waste to Recycling** | **Amount (Kgs)** |
| Tetrapak | 205 |
| Plastic PE-HD | 1,212 |
| Plastic PS | 959 |
| Paper newspapers | 147 |
| Recovered waste | 1,398 |
| Plastic PE-LD | 6,998 |
| Paper magazines | 81 |
| Metal Foil | 26 |
| Plastic Hi-PS | 6 |
| Plastic - High Impact PS | 13 |
| Food Waste | 153,390 |
| Plastic lids | 5 |
| | |
| **Waste to Landfill** | **Amount (Kgs)** |
| General Waste | 66,360 |

*Table 3: A table illustrating the amount of waste generated in one year by the organization this research is based on for store 2.*

| Annual Waste Generated | |
|---|---|
| **Waste to Recycling** | **Amount (Kgs)** |
| Cardboard K4 | 89,140 |
| Organic waste | 21,290 |
| Recovered waste | 37,925 |
| Plastic sticky | 2,994 |
| Paper common mix | 5,149 |
| Metal cans | 430 |
| Plastic (PET, PP, PE-HD and PS) | 4,398 |
| Glass | 180 |
| Paper newspapers | 359 |
| Plastic PE-LD | 1,790 |
| Food Waste | 145,824 |
| Tetrapak | 1,059 |
| | |
| **Waste to Landfill** | **Amount (Kgs)** |
| General Waste | 123,478 |

Below are the results from the software simulation from each of the steps discussed in Chapter 4.2. In this chapter, the results will be briefly discussed. An in-depth analysis of the results will be provided in Chapter 4.

### 3.3.1. Store 1

- **Step 1:**
  - As this research focused on food waste as a source of energy in a waste-to-energy system, the biomass performance model was selected for this step. No financial model was selected for this software simulation.

- **Step 2:**
  - As previously indicated, none of the South African cities are listed on SAM. An alternative city with similar weather conditions had to be selected. Los Angeles was selected on SAM for this step, as the latitude and longitude information is the same as that of Cape Town.

- **Step 3:**
  - For this step, the amount of food waste generated in Table 1 had to be computed into the Dedicated Energy Crops component of the software. The food waste was computed under 'Herbaceous crop', as most of the food waste is fruits and vegetables. The total amount of food waste was **153.39 bone dry tons/ year** with a moisture of 16% and resource availability of 80%. These figures were estimated for this research. The SAM software converts the amount of waste computed by the user into the total obtainable biomass resource based on the resource obtainable and moisture figures. The converted figure is **122.712 dry tons/ year**.

- **Step 4:**
  - Based on the amount of waste computed in the previous step, the total estimated plant capacity was calculated by the software. With the data used in step 3, the total capacity for this system was estimated to be **19.5806 kW**. The total energy produced by the system will be discussed in Chapter 4.

- **Step 5:**
    - With boiler steam grade of **428.222° C/ 900 psi**, this system produced an estimated **54.20 kg/ hour of steam**. It should be noted that two boilers were used in this system simulation. In Table 4, the losses and the efficiency of the system were illustrated.

*Table 4: Estimated efficiency losses of the simulated waste to energy system for store 1*

| **Estimated Efficiency Losses** | |
|---|---|
| **Type of Loss** | **Percentage** |
| Dry flue gas losses | 9.14547 |
| Moisture in fuel | 2.8726 |
| Latent heat | 3.88971 |
| Unburned fuel | 3.5 |
| Radiation and miscellaneous | 2.03 |
| **Total boiler efficiency** | **78.5622** |

- **Step 6:**
    - The life cycle impact specifications for this simulated system are not as intense as they would have been if the system was based on a non-renewable energy source or if there was a lot of transportation involved. The vehicle selected in this simulation used diesel as a fuel; and the waste is collected from the store to the waste-to-energy plant in a single trip. As a result, the electricity grid carbon intensity was estimated to be **643g $CO_2$ eq/kWh**.

The organisation that was contacted for data for this research provided data for two of their stores. The following results will briefly indicate the results, as per the steps above, for the second store.

### 3.3.2. Store 2

- **Step 1:**
  - The biomass performance model was selected for this simulation. No financial model was selected.

- **Step 2:**
  - A city with similar climatic conditions to Cape Town in the list provided in SAM was Los Angeles. This was selected as the location for this simulation.

- **Step 3:**
  - The total amount of food waste was **145.82 bone dry tons/ year** for the second store. With a moisture value of 16% and 80% resource availability of 80%, the total obtainable biomass resource was **116.659 dry tons/ year**.

- **Step 4:**
  - The total estimated capacity of the simulated system was **18.6148 kW**. This is based on the input waste data provided for this research.

- **Step 5:**
  - The same boiler specs as store 1were selected for store 2. With a steam grade of **428.222° C/ 900 psi,** the system produced **51.53kg/ hour of steam**. The estimated efficiency table for store 2 is similar to that of store 1. The reason for this is that the same boilers were used for both stores in SAM. This means the total system efficiency for store 2 was **78.5622%**.

- **Step 6:**
  - The electricity grid carbon intensity for store 2 was estimated to be **643g $CO_2$ eq/kWh**.

The following chapter will discuss detailed results of the system simulation with graphs and tables.

# CHAPTER 4: RESULTS AND DISCUSSION OF RESULTS

## 4.1. Introduction

In Chapter 3, a detailed software simulation process was explained, but the system results after the simulation were not provided. This chapter provides the system results for both stores that were used in this research, and a detailed discussion of the results from the software simulation.

Summary table for both stores will be included in this chapter. These summary tables indicate the annual energy, annual biomass usage and the capacity factor for each of the two systems simulated.

Results that will be presented in this chapter include:

- Monthly energy generated (in kWh)
- Monthly gross heat rate (in MMBtu/ MWh)
- Monthly boiler efficiencies (in %)

There are many uses that the energy generated can be used for. These include refrigeration, lighting and water heating and cooling. These will be discussed in greater detail later in this chapter.

From the perspective of a system operator, it is important to take note of the gross heat rate and the boiler efficiencies monthly. This ensures that the system is fully operational and that any issues with the system are detected before they cause issues with the operation of the systems.

Monthly energy will be presented in this research to clearly indicate the amount of electricity that would likely be generated through the small-scale WtE plant. This is important to know, as this will inform the type of equipment and appliances to procure for the store using the plant.

The gross heat rate is presented in these results to illustrate the amount of heat the system will give off to determine whether the system be used for building heating and cooling.

Boiler efficiency is also presented in these results to illustrate the efficiency of the different boilers simulated in this software. This will assist in ensuring that the correct boilers are used to avoid the costs of always replacing boilers when it is discovered that the ones used are not performing as they should.

## 4.2. System Results

### 4.2.1. Store 1

There are several forms of results that the user can create using the SAM software. This sub-chapter provides the detailed tables and graphs that illustrate various results from the system simulation.

Table 5 provides a summary of the simulation results for one year. As illustrated in the table, the estimated annual energy produced by the simulated system, with the food waste as a source, is 138,509 kWh.

A graph illustrating the monthly energy consumption will be included in this chapter.

*Table 5: A summary table illustrating results from the software simulation*

| **Summary Table** | |
|---|---|
| **Metric** | **Value** |
| Annual energy (year 1) | 138,509 kWh |
| Annual biomass usage (year 1) | 123 dry tons/year |
| Capacity factor (year 1) | 80.80% |

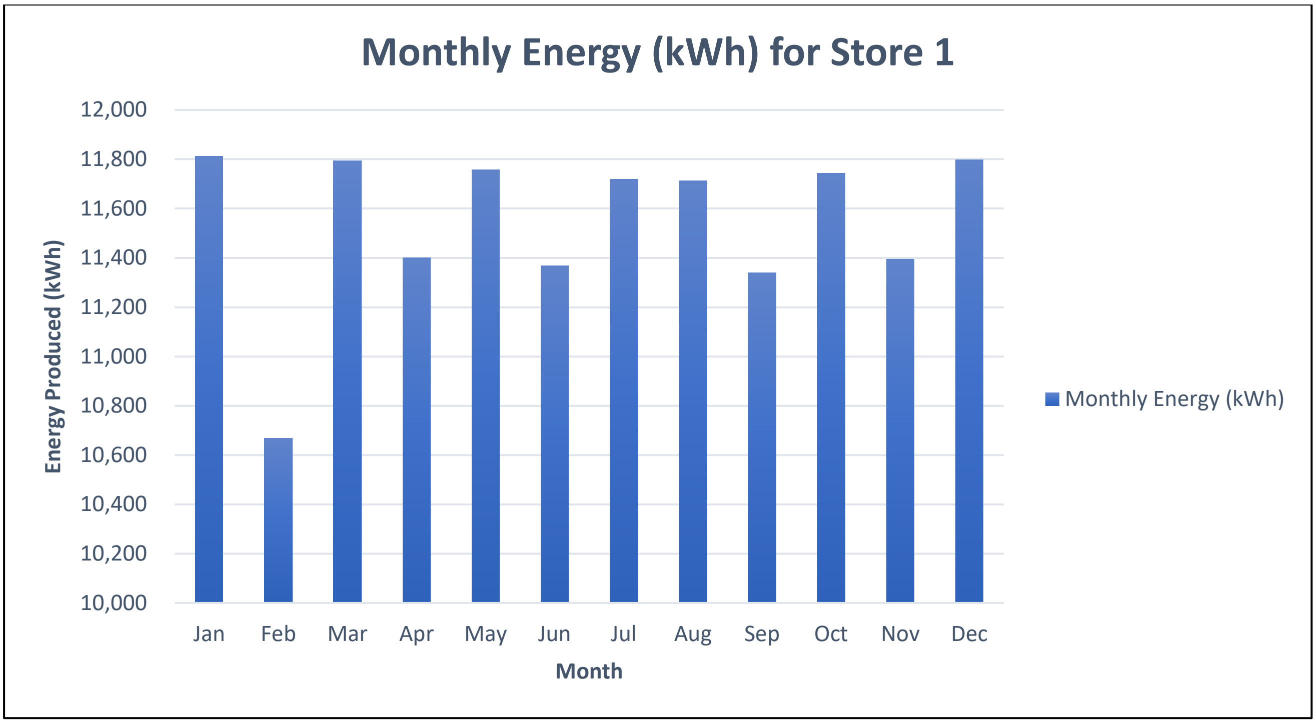


*Figure 12: Monthly energy (in kWh) produced by the simulated system for Store 1.*

Looking at the monthly energy generated by the system, there are numerous ways in which this energy can be used. These will be discussed further in section 4.3 of this chapter.

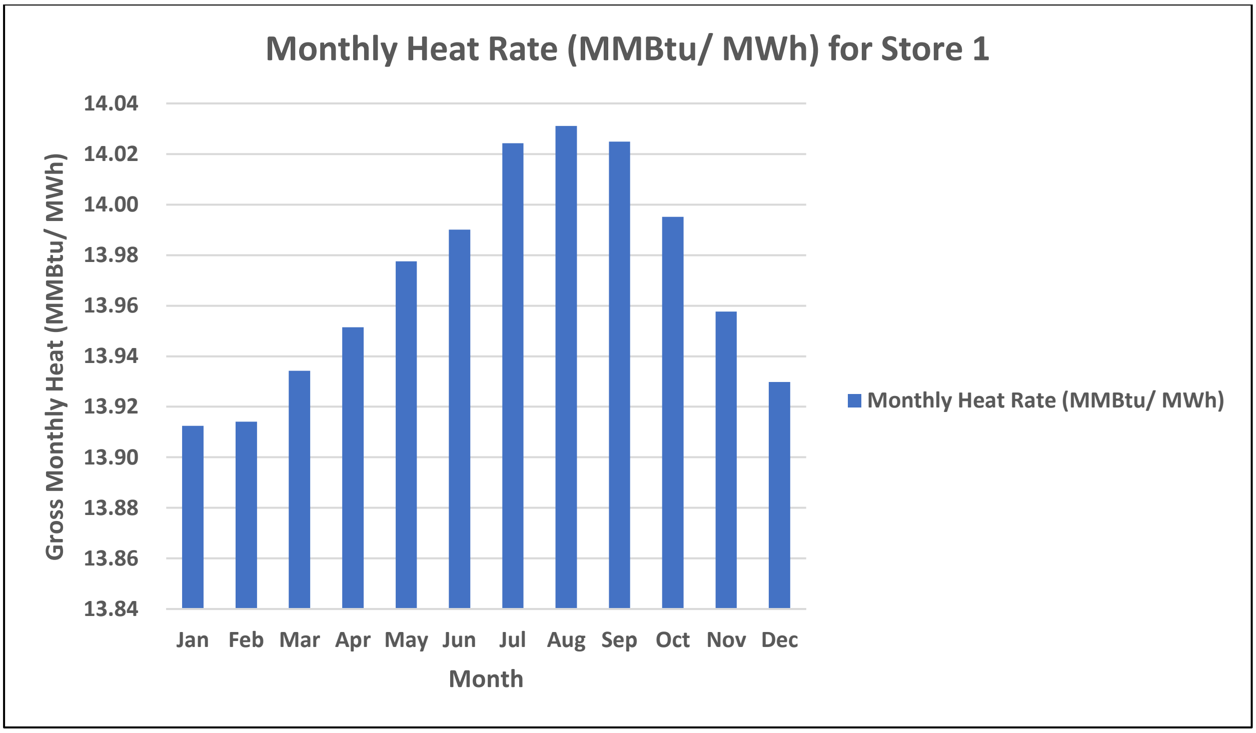


*Figure 13: A graph illustrating the gross monthly heat rate for the simulated system for Store 1.*

Figure 13 is an illustration of the monthly heat rate of the system for Store 1. Simply put, heat rate refers to the ratio between heat input and energy output. Usually used in reference to a coal-fired power plant, this term can be used for a WtE system, as the operation of these two systems is more or less similar.

*Table 6: A table illustrating the monthly efficiency of the system for Store 1*

| **Total Monthly Boiler Efficiency (%)** | |
|---|---|
| **Month** | **Monthly Boiler Efficiency (%)** |
| Jan | 73.92 |
| Feb | 73.90 |
| Mar | 73.97 |
| Apr | 74.02 |
| May | 74.09 |
| Jun | 74.12 |
| Jul | 74.24 |
| Aug | 74.25 |
| Sep | 74.26 |
| Oct | 74.16 |
| Nov | 74.05 |
| Dec | 73.98 |

System efficiency is one of the most important factors to consider, especially at the software simulation stage of the project. The reason for this is that it provides the user with an idea of how the system will perform. It is important to determine the system efficiency before project implementation, so project developers and funders determine if the project will yield the desired results.

### 4.2.2. Store 2

The results for Store 2 are not much different from the results for store 1. The reason for this is that there is not much difference in the amount of waste generated by the stores. Table 7 provides a summary of the system results for Store 2. Detailed results will be illustrated in this section.

*Table 7: A table providing a summary of the system results for Store 2*

| **Summary Table** | |
|---|---|
| **Metric** | **Value** |
| Annual energy (year 1) | 131,677 kWh |
| Annual biomass usage (year 1) | 117 dry tons/year |
| Capacity factor (year 1) | 80.80% |

Figure 14 illustrates the monthly energy that would ideally be generated by the system with the specified amount of waste from Store 2.

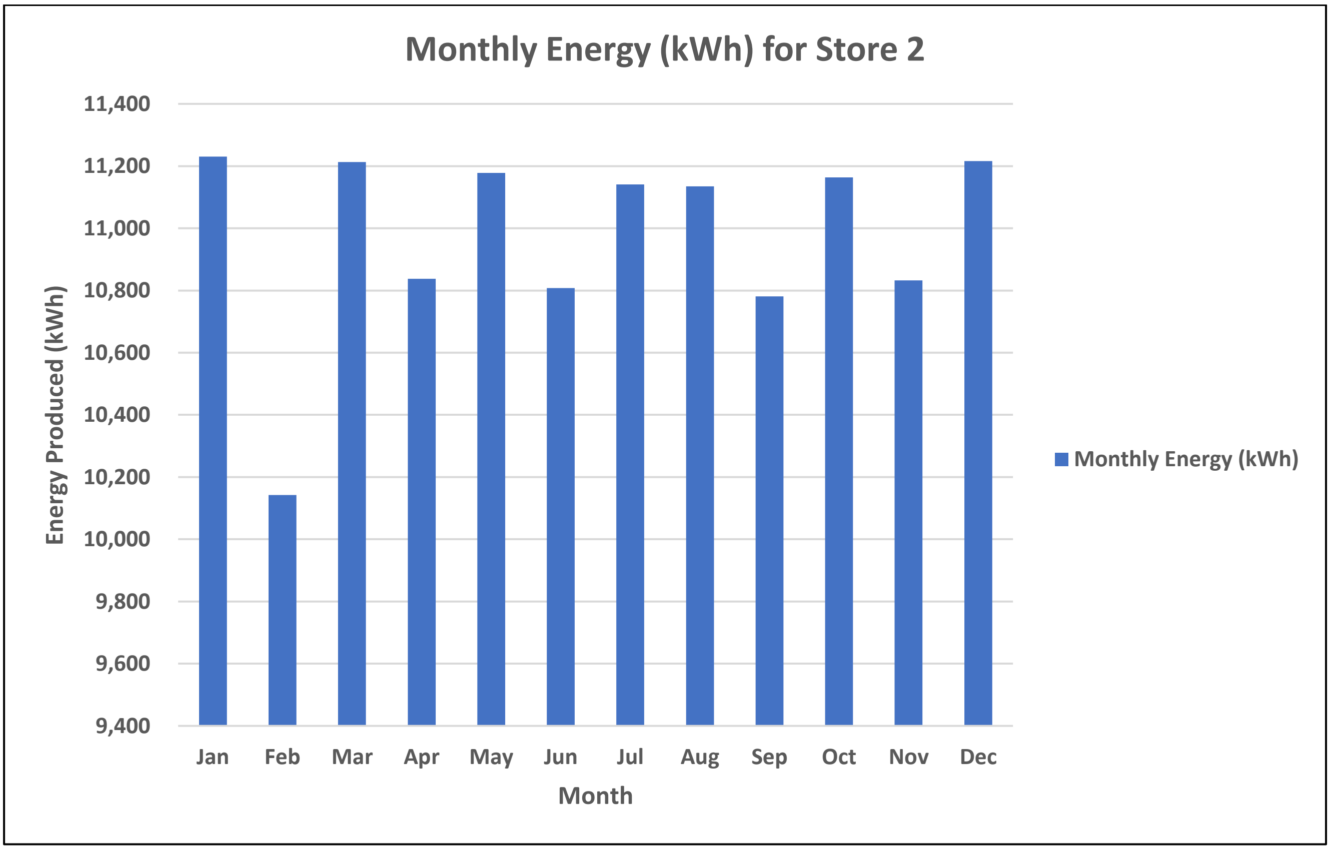


*Figure 14:A graph illustrating the monthly energy generated by the simulated system for Store 2.*

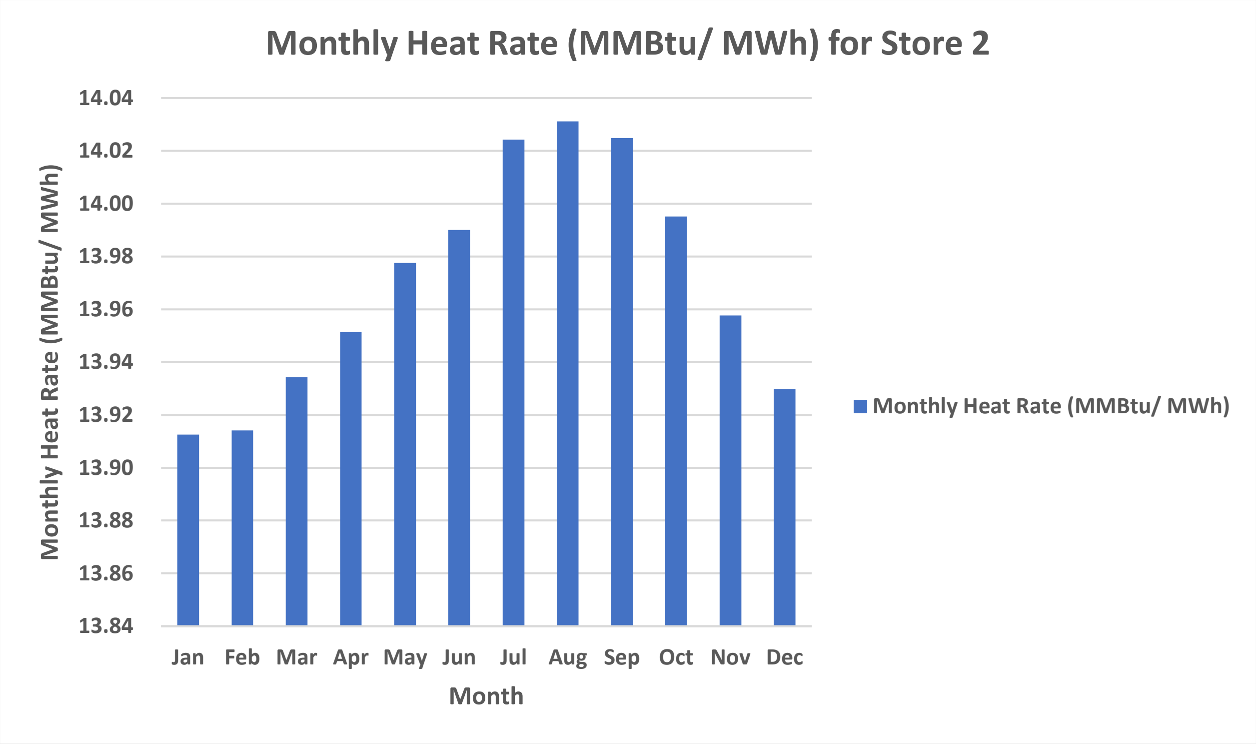


*Figure 15: A graph illustrating the monthly heat rate for the system for Store 2.*

*Table 8: A table illustrating the total monthly boiler efficiency for Store 2*

| **Total Monthly Boiler Efficiency (%)** | |
|---|---|
| **Month** | **Monthly Boiler Efficiency (%)** |
| Jan | 73.92 |
| Feb | 73.90 |
| Mar | 73.97 |
| Apr | 74.02 |
| May | 74.09 |
| Jun | 74.12 |
| Jul | 74.24 |
| Aug | 74.25 |
| Sep | 74.26 |
| Oct | 74.16 |
| Nov | 74.05 |
| Dec | 73.98 |

Considering the graphs and tables presented in this section, section 4.3 provides a detailed explanation of these results.

## 4.3. Discussion of Results

The system, which was simulated using SAM, provided several results that are useful to have when considering a project of this nature. For simplicity and for the projects in this research, only the following will be discussed:

- Monthly energy (in kWh)
- Monthly heat rate (in MMBTU/ MWh)
- Monthly boiler efficiency (in %)

It should be noted that since two stores were used in this research, the discussion of the results will be grouped according to the three above-mentioned components. Another point that should be noted is that the energy generated by the systems is the focal point of these results and the discussion of results. For this reason, more information will be provided, as compared to the monthly heat rate and the monthly boiler efficiency.

### 4.3.1. Monthly Energy (in kWh)

Considering the aim of this research, this is the most important results that needs to be discussed. The reason for its importance is that it provides the researcher and other stakeholders with an overall indication of the total electricity that the proposed systems would produce.

Suggestions for how the electricity generated using the simulated systems can be used include lighting for stores; air conditioning; refrigeration; or for powering other equipment in the stores. Assuming there are many appliances that can be powered using this electricity, an energy audit would have to be conducted to identify opportunities for using this electricity.

During an energy audit, a walk-through exercise of the stores in question would be conducted. The reason for this would be to do a tally of all the equipment in the stores; the number of light fittings; types of light fittings; and the types of air conditioning units there are at the store. Once this information is collected, accurate estimate, based on the stores' operating hours, would be made. Once the results have been determined, opportunities for using the generated electricity would be identified.

The implementation of renewable energy and energy efficiency measures requires lengthy administrative processes. However, once the administration has been dealt with, the process runs efficiently.

As indicated in the previous sub-section, the total annual energy generated for Store 1 and Store 2 is 138,509 kWh and 131,677 kWh, respectively.

# CHAPTER 5: KEY FINDINGS AND CONCLUSION

## 5.1. Conclusion

The focal point in this research was the use of food waste (in tonnes per year) in a software to simulate how much electricity would be generated for a year. With the back-end calculations previously done by the software developers, this enabled the user to determine the amount of electricity that would be generated, should the organisation opt to use their waste to generate electricity as an off shoot of this research.

The results in chapter 4 provides a detailed explanation of the graphs that were generated using the software results. The three components discussed in these results are listed below:

- Monthly energy generated (in kWh)
- Monthly gross heat rate (in MMBtu/ MWh)
- Monthly boiler efficiencies (in %)

These figures were simulated in chapter 3, where detailed steps of how the software can be used to simulate a renewable energy project, with emphasis on a biomass project.

From the results discussed in Chapter 4, the objectives set out in Chapter 1 have been fulfilled. Below are the objectives:

- To understand the feasibility of using food waste for electricity generation.
    - To understand how much food waste can be used to generate electricity for WtE system.

The one component discussed in the results is the monthly energy generated by the software. As indicated in the results, an annual amount of **138,509 kWh** and **131,677 kWh** for both Store 1 and Store 2, respectively. Monthly averages for these two stores are **11,542 kWh** for Store 1 and **10,973 kWh** for Store 2.

The software used for this research, SAM, allows the user to select a range of data for the input stage. This data includes the types of crops used in the software to generate electricity using the various WtE technologies. These types of crops include the following:

- **Traditional biomass:**
    - Bagasse
    - Barley straw
    - Corn stover
    - Rice straw
    - Wheat straw
    - Forest residue
    - Mill residue
    - Wood residue
- **Dedicated energy crops**
    - Woody crops
    - Herbaceous crops

Taking into account the fact that none of these were found in the types of waste generated by the two stores focused on in this research, an assumption that food waste was a form of an herbaceous crop was made.

Once this information, together with a range of other information, was inputted into the software, the simulation could be run, and the results could be produced and exported onto a Microsoft Excel format for better analysis by the user.

From the results in the software simulation, it is evident that with the correct technology, waste-to energy in the commercial food retailing sector can be achieved. This would reduce the amount of waste taken to landfill sites.

## 5.2. Problems Encountered

During this research, there were a few challenges that were encountered. These will be discussed in this sub-section.

### 5.2.1 Determining the appropriate type of biomass to use

Many of the software that were explored before SAM was chosen for this research required specific types of biomass for the simulation. This made it challenging to model the desired system that will address the main aim of the research. The alternatives that were provided in the other software would have required additional requirements for the research, which would be an issue, as time would have been a constraint. The reason food waste was chosen as the type of biomass used in this research is that historic waste data was readily available. This means that it was not necessary to manually collect this data, which would have taken more time that there was available.

### 5.2.2 Finding an organisation that was willing to provide data

Several food retailing organisations in the Western Cape were contacted for data that would be used in this research. Most of those organisations did not have the required information/ data readily available. The organisation used in this research was one of the four organisations that were contacted that had the required data.

### 5.2.3 Choosing the correct graphs for the results

The software used for this research provides the user with many options for graphs to create once the software simulation is complete. These include monthly energy, monthly power block efficiency, monthly temperature and monthly relative humidity, to name a few. This made it challenging to select graphs that are applicable to the research.

With each of these challenges, resolutions were found, and research was completed.

## 5.3. Future Work

Since there has been work done in the WtE industry and a small section of the industry was covered in this research, there is still great room for research that can be found in this research. Future research areas include the following:

- Focusing on the fisheries and restaurants sectors to determine the feasibility of implementing WtE. Should WtE be implemented in the above-mentioned sectors, there would be less food waste going to landfills, and food waste statistics in South Africa would decrease.

- Construction of a prototype of a small-scale WtE system discussed in this research could be constructed to demonstrate how the system would work if it were to be implemented, how much land space would be required for it, and how to maintain the system. Due to time and technology constraints, a prototype could not be implemented in this current research.

- Focusing on the financial analyses of a small-scale WtE project would provide organisations with an idea of what costs would be involved in implementing such a project.

- Using at least three different software to compare results for the same project. This would provide an idea of how a project would perform, should it be implemented. Using different software for the same project would also provide an analysis of the accuracy of using software for the simulation of renewable energy projects.

With these recommended future research areas, the WtE sector would benefit and the market would open for a range of new technologies being developed and employed.

## Appendices

APPENDIX 1: An image illustrating the process of Mass burning (left) and RDF (right) (Stringfellow, 2014)

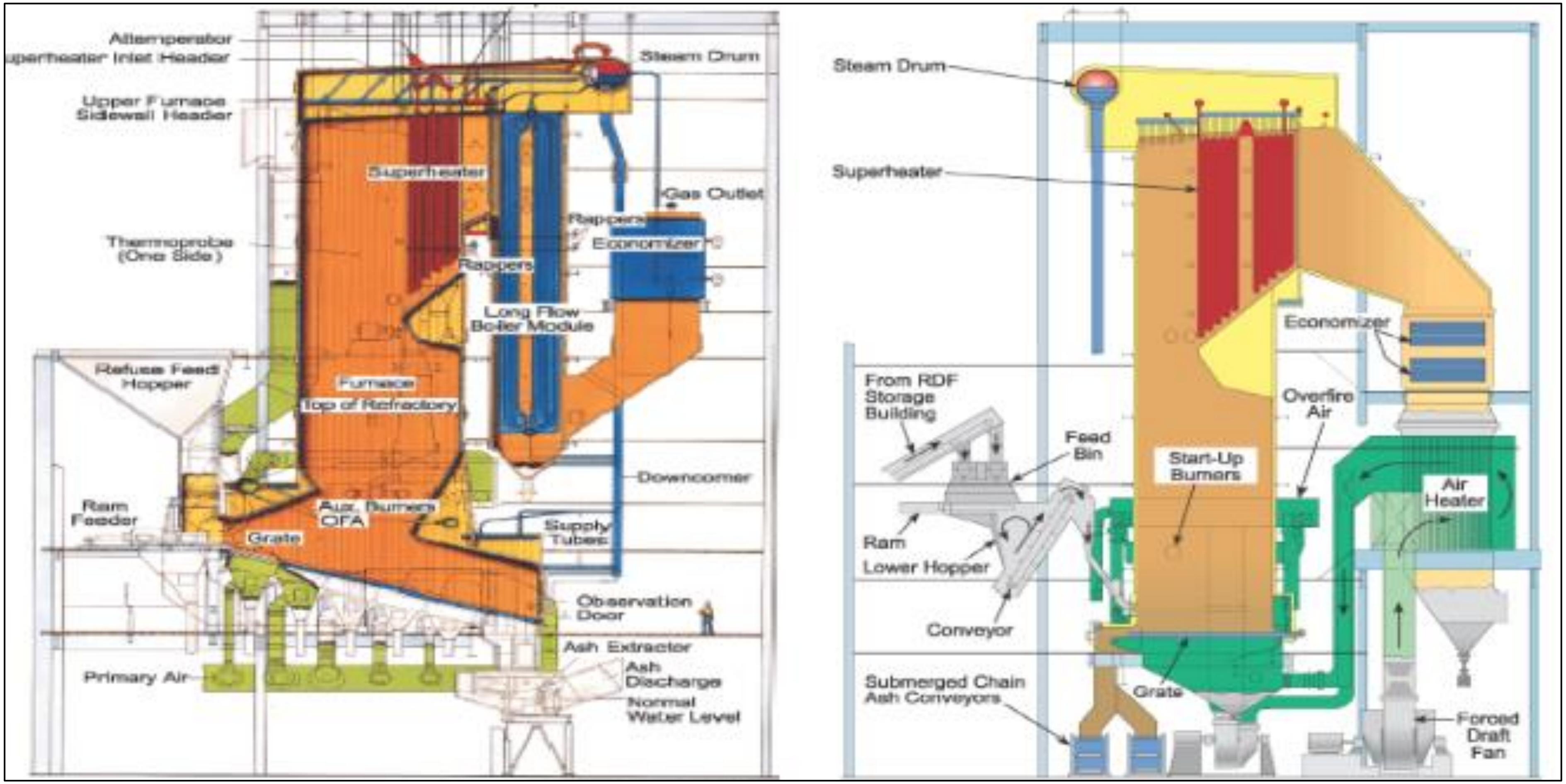


*Figure 16: An image illustrating the process of Mass burning (left) and RDF (right) (Stringfellow , 2014).*

APPENDIX 2: An image illustrating a detailed pyrolysis process from feedstock (Waste to Energy International, 2017).

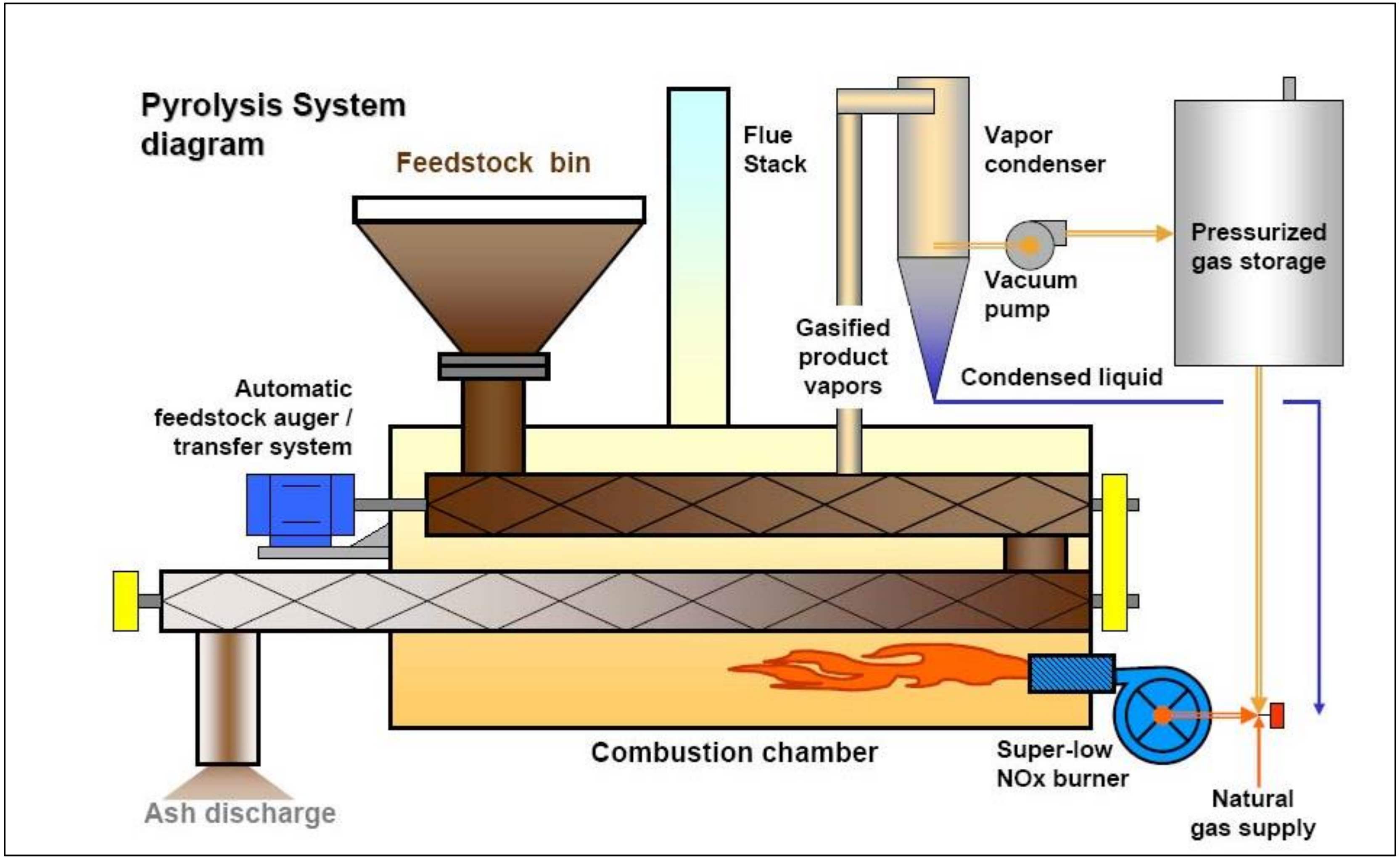


*Figure 17: An image illustrating a detailed pyrolysis process from feedstock (Waste to Energy International, 2017).*

APPENDIX 3: An image illustrating a detailed gasification process from municipal solid waste (Tan, 2013)

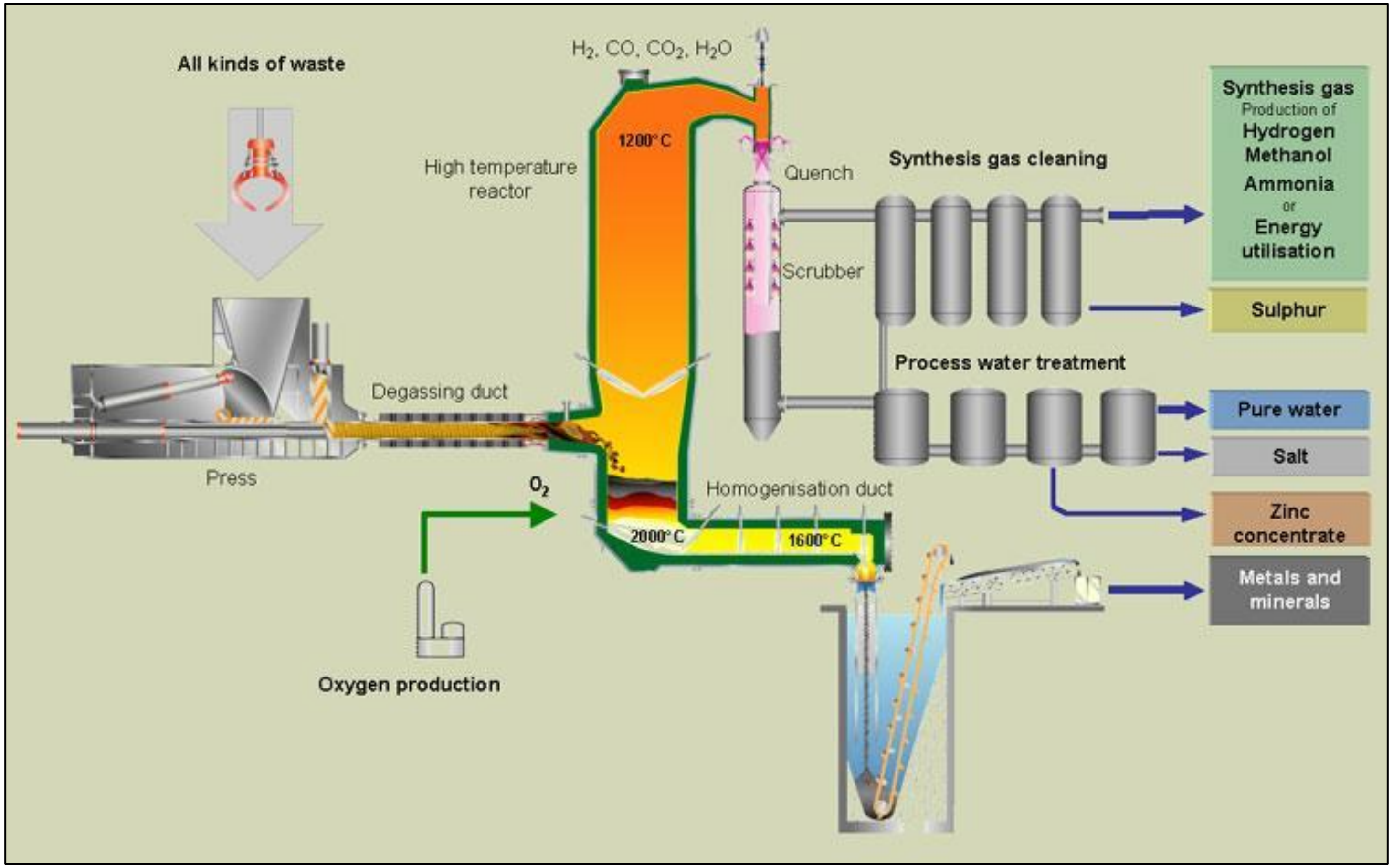


*Figure 18: An image illustrating a detailed gasification process from municipal solid waste (Tan, 2013).*

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