A FINANCIAL FEASIBILITY STUDY OF WASTE TO ENERGY GENERATION IN THE CITY OF CAPE TOWN

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Acronyms

AD – Anaerobic Digestion

ANC – African National Congress

CoCT – City of Cape Town

DME – Department of Minerals and Energy

EPA – Environmental Protection Agency

GHG – Greenhouse Gas

IDP – Integrated Development Plan

ISWM – Integrated Solid Waste Management

IWM – Integrated Waste Management

MRF – Material Recovery Facility

MSW – Municipal Solid Waste

MW - Megawatt

NERSA – National Energy Regulator of South Africa

NPW – Net Present Worth

NWMS – National Waste Management Strategy

ROI – Return on Investment

UNFCCC – United Nations Framework Convention on Climate Change

WtE – Waste to Energy

Glossary

Anaerobic digestion

A method of composting that does not require oxygen. This composting method produces methane.

Ash

The non-combustible solid by-products of incineration or other burning process.

Collection

The process of picking up wastes from residences, businesses, or a collection point, loading them into a vehicle, and transporting them to a processing, transfer, or disposal site.

Combustion

In MSWM, the burning of materials in an incinerator.

Composting

Biological decomposition of solid organic materials by bacteria, fungi, and other organisms into a soil-like product.

Disposal

The final handling of solid waste, following collection, processing, or incineration. Disposal most often means placement of wastes in a dump or a landfill

Energy recovery

The process of extracting useful energy from waste, typically from the heat produced by incineration or via methane gas from landfills.

Hazardous Waste

Waste that is designated such by regulatory agencies either because it has elevated levels of hazardous chemicals or materials, because it exhibits a potentially dangerous characteristic (e.g., ignitable, corrosive, etc.) or because the material belongs to a general family of materials which have been deemed hazardous by regulatory agencies.

Incineration

The process of burning solid waste under controlled conditions to reduce its weight and volume, and often to produce energy

Integrated Solid Waste Management

A comprehensive waste prevention, recycling, composting, and disposal program. An effective ISWM system considers how to prevent, recycle, and manage solid waste in ways that most effectively protect human health and the environment.

Landfill gases

Gases arising from the decomposition of organic wastes; principally methane, carbon dioxide, and hydrogen sulfide. Such gases may cause explosions at landfills.

Landfill

A modern engineered way to deposit waste into the ground and still protect the environment. Landfills are accounted for a separate line of business within the WM organization. Different types of landfills include MSW, C&D, Asbestos Monofil, Ash Monofil, Special Waste and Hazardous Waste.

Leachate

Liquids that have come in contact with waste. Leachate accumulates in the waste footprint of the landfill. Leachate levels within the landfill must be monitored and cannot exceed state regulatory agency established levels.

Materials Recovery Facility (MRF)

Line of business where recyclable material is processed, separated, and sold. This is a facility where recyclable materials are sorted and processed for sale.

Methane

A gas by-product generated through natural decomposition of solid waste in landfills. This gas is monitored to maintain state regulatory agency levels. Accumulated gas is either burned off using a flare or is converted to energy by use of a gas plant.

Municipal Solid Waste (MSW)

"Regular" rubbish from non-industrial sources, such as residential homes, restaurants, retail centres, and office buildings. Typical MSW includes paper, discarded food items, and other general discards. Green waste is considered MSW and includes yard clippings, leaves, trees, etc.

Organic waste

Technically, waste containing carbon, including paper, plastics, wood, food wastes, and yard wastes.

Recyclables

Items that can be reprocessed into feedstock for new products. Common examples are paper, glass, aluminium, corrugated cardboard, and plastic containers.

Recycling

The process of transforming materials into raw materials for manufacturing new products, which may or may not be similar to the original product.

Refuse-derived fuel (RDF)

Fuel produced from MSW that has undergone processing. Processing can include separation of recyclables and non-combustible materials, shredding, size reduction, and pelletizing.

Solid Waste

"Regular" garbage from non-industrial sources, such as residential homes, restaurants, retail centres, and office buildings. Typical MSW includes paper, discarded food items, and other general discards. Green waste is considered MSW and includes yard clippings, leaves, trees, etc.

Tipping fee

A fee paid by anyone disposing of waste at a landfill.

Waste management hierarchy

A ranking of waste management operations according to their environmental or energy benefits. The purpose of the waste management hierarchy is to make waste management practices as environmentally sound as possible.

Waste Stream

Specific types of waste found in customer's disposal (trash, cardboard, aluminium, metal, etc.) or a more broad definition of disposal type. (e.g. MSW, C&D, Hazardous, etc.)

Executive Summary

In recent years, Cape Town has been exposed to two crises: electricity supply that is unreliable; and increasing waste generation that threatens to spiral out of control. The current electricity generating infrastructure is struggling to keep pace with economic development and population growth, not only in Cape Town, but throughout South Africa. Similarly, current waste management practices are now being put to the test and municipalities are trying to implement strategies that will keep pace with a City trying to take itself forward into the 21st Century. This change of waste management strategy and electricity supply constraint provides the perfect situation to test whether waste-to-energy (WtE) technologies can help address these issues in an efficient and sustainable manner.

Waste-to-energy potentially represents a means to dispose of municipal solid waste, produce energy, recover materials, and free up scarce land that would otherwise have been used for landfilling. The objective of this research is to examine what the city of Cape Town has undertaken regarding its municipal solid waste (MSW) and to investigate the financial feasibility of WtE as a source of energy and a key component of integrated solid waste management for the City.

The significance of this study is that, although analysed in isolation, WtE technologies are evaluated as part of the infrastructure required for an integrated waste management system. Many studies in the past have only concentrated on the financial performance of a technology in isolation without considering its impact on a waste management system and the infrastructure that is required for successful implementation. This has led to incomplete and uninformed conclusions as to the feasibility of WtE. A systems approach has thus been adopted for this study, looking at other “links” in the chain, such as source separation, the continued need for landfill sites and mechanical handling systems. Each of these “links” helps to integrate WtE into an effective and sustainable waste management programme. Further merit to the study is achieved by financially analysing both thermal (incineration and gasification – use heat or combustion to treat wastes) and non-thermal (small and large scale anaerobic digestion – whereby methane and carbon dioxide rich biogas is produced that is suitable for energy recovery) WtE technologies. Thermal waste-to-energy technologies use heat or combustion to treat wastes. A non-thermal process of WtE is one whereby methane and carbon dioxide rich biogas is produced that is suitable for energy recovery. This occurs when microorganisms break down biodegradable material in the absence of oxygen.

The research revealed a number of interesting results. First, financially all WtE technologies are viable as shown by positive net present worths and returns on investment if considered in isolation

under the set of assumptions described in this thesis. Secondly, when considered as part of an integrated system, incineration and centralized anaerobic digestion are seen as the best WtE performers in terms of the cost of processing and disposing of one ton of MSW. This is not to rule out the other options. The recommendations look at the optimal mix of thermal and non-thermal technologies that could also be implemented as part of an integrated system.

Table 1: Summary of pathways from most attractive to least attractive

Pathway	Node	Waste Input	Cost/ tonne waste generated (figure is rounded)
1 (business as usual)	2	1 tonne	R600/t
6 (incl. Incineration)	2 + 3	1 tonne	R661/t
4 (incl. Centralised AD)	2 + 4 + 6	1 tonne	R678/t
3 (incl. Gasification)	2 + 4 + 5	1 tonne	R824/t
5 (incl. Decentralised AD)	1 + 2 + 7	1 tonne	R949/t
2 (incl. incineration	1 + 2 + 3	1 tonne	R1008/t

Peach = most attractive; yellow = attractive; orange = less attractive; red = least attractive

Table 1 highlights the most attractive pathway to the least attractive pathway. No WtE pathway outperforms waste going to landfill financially. Pathways including incineration and centralized anaerobic digestion facilities are the optimal WtE performers and therefore should be considered for implementation. Even though landfill continues to be the cheapest option, it is not economically and environmentally sustainable and increases the need for more land. Also, without proper investment, valuable material recovery does not always take place at landfill. WtE technologies, both thermal and non thermal, decrease the need for more landfill and the amount of waste going to current landfill, subsequently saves land and creates revenue streams including electricity generation that will address Cape Town current energy vulnerabilities.

The pathway analysis also revealed results that were different from those gathered from the isolated technology assessment that took place. When integrated into a system, centralized AD became one of the better performing technologies financially. Incineration in isolation was the strongest in terms of financial perfomance. It was considered as part of two separate pathways. The first maintained its strong position while the second made it part of the weakest performing pathway. Decentralised AD, which was one of the strongest technologies in terms of financial perfomance, became one of the weakest when evaluated as a component of a pathway. Gasification was the weakest technology in isolation but improved to be included in the fourth best pathway option. This shows that the pathway approach adds value and proves that analysing a technology in isolation does not always reflect the best option going forward. Rather one must consider these technologies as part of a system thereby obtaining results that are a more realistic reflection of what a technology is capable of.

The inputs that were used for the models show trends that were gathered from academic literature and industry experts. The models that were created to carry out this financial analysis are thus used to demonstrate methodology and should not be used to support any business decision making. If a technology company or government department has recent and reliable data, the model can then be used to calculate the relevant indicators.

Chapter 1: Introduction

This thesis gives coverage to the potential of available waste-to-energy technologies to help alleviate the pressure that South Africa's current energy crisis is putting on the City and to mitigate the solid waste problem in the City of Cape Town. In several other nations waste-to-energy has been shown to be an effective, environmentally sound, and economically beneficial means for processing municipal solid wastes and recovering energy (refer to case studies mentioned in Section 4 – Spain, Japan). The objective of this research is to examine what the city of Cape Town has undertaken regarding its municipal solid waste (MSW) and to investigate the financial feasibility of WtE.

Cape Town is the focal point of the study because of its growing population, consumption trends, energy needs and limited availability of space for waste disposal. Furthermore, whilst Cape Town's current waste disposal options are adequate, the City is taking major steps to incorporate reuse, recycling and source separation initiatives into their current waste management programme. This waste management infrastructure is in the process of being put in place, with various pilot schemes being rolled out. Much change is underway for waste management in Cape Town (recycling drives and potential new landfill sites around the City) and successful implementation of waste-to-energy as part of an overall integrated solid waste management approach may serve as an example to not only other urban areas in South Africa but also to cities in other developing countries.

1.1 Aim and objectives of study

The main aim of the study is to investigate the financial feasibility of WtE with the objective of showing the financial viability of including WTE as a key component of integrated solid waste management for the City of Cape Town. This financial feasibility will be carried out in two stages. The first stage will be a financial analysis of two thermal and two non-thermal WtE technologies in isolation. Thermal waste-to-energy technologies use heat or combustion to treat wastes. A non-thermal process of WtE is one whereby methane and carbon dioxide rich biogas is produced that is suitable for energy recovery. This occurs when micro-organisms break down biodegradable material in the absence of oxygen.

The following linking objectives of the study will also be investigated:

- Provide the audience with evidence that WtE can be a suitable solution to Cape Town's waste issue whilst providing a renewable source of energy.

- Show the merit of pathway analysis and how it can be used to evaluate WtE technologies not just in isolation but also as part of a system

1.2 Research Hypotheses

Research Hypothesis 1: WTE technologies can play a role in the ISWM of the City of Cape Town

Research Hypothesis 2: Pathway analysis approach is a relevant tool to evaluate the WtE feasibility

1.3 Methodology

WtE technology analysis is often considered in isolation and many studies do not incorporate the waste system infrastructure that is needed for full-scale implementation. This study not only looks at non-thermal and thermal WtE technologies from a financial perspective but also looks at the waste management infrastructure required to ensure the execution of a specified technology. For the purposes of this study this infrastructure includes landfill sites, source separation initiatives and mechanical handling systems, each of which are also analysed in terms of their financial performance. This provides considerable depth and strength to the study and enables the reader to not just consider a technology but a holistic system that could be implemented.

The isolated results will be used for financial analysis of WtE as part of an integrated solid waste management system. By carrying out a pathway analysis, it will be shown that if WtE technologies are to be considered as an option for decision makers and investors, technologies must be analysed both in isolation and part of a system.

The results of the study will be based around the performance of identified “pathways for municipal solid waste”. These pathways will incorporate the infrastructure required for successful implementation of a specific WtE technology, looking closely at the cumulative financial impacts of each pathway. This will create a comparable indicator for each pathway, providing insight into which pathway is the most consistent performer and therefore establishing which pathway is most optimal for implementation and which should not be considered.

As the focal point of this study is WtE technologies, a number of financial models have been created that look at the performance of technologies over a specified lifespan. These models include capital expenditures, operating expenditures and revenues that a technology can generate. These variables in turn lend towards the calculation of indicators that highlight financial performance and whether there should be investement in a technology or not. This is important to establish, as a technology needs to be financially viable as an isolated entity before it can be incorporated into a pathway.

These results will then be considered as part of a cumulative study of identified pathways. The models that were created to carry out this financial analysis demonstrate methodology and should not be used as a rule. The inputs that were used for the models show trends that were gathered from academic literature and industry experts. If a technology company or government department has recent and reliable data, the model can then be used to calculate the relevant indicators.

Chapter 2: The Case for Waste-to-Energy in South Africa

2.1 Background

This section discusses the various energy, waste, economic and population pressures that South Africa is facing that could signal a need for the introduction of waste-to-energy technologies. As South Africa's economy continues to grow the populations standard of living will improve. As this happens the amount of waste generated will increase (EEA 2010), as will the amount of energy demanded (Stern, 2003) by the ever increasing affluent population.

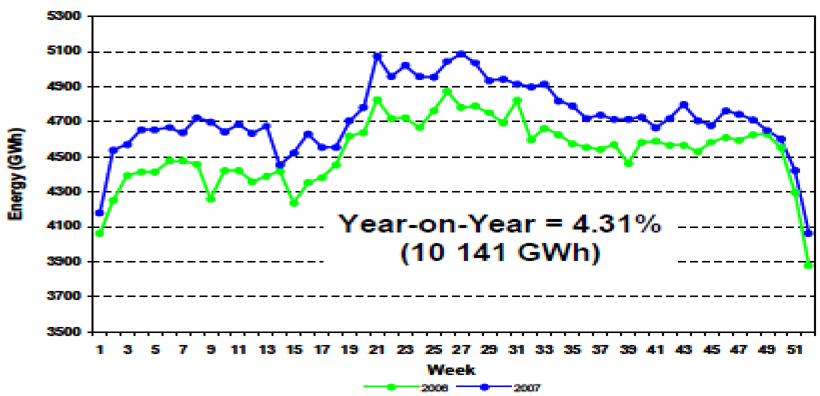
Stresses will begin to take its toll on the country in terms of electricity generation and on the land used for disposal of waste. This can lead to environmental pollution from both activities, increasing the risk to public health and safety. This section makes the case for waste-to-energy in South Africa by looking at the impacts of these technologies as applicable to South Africa and discusses the energy potential available from WtE projects.

2.2 Energy pressures facing South Africa

2.2.1 South Africa's Electricity Demand

Two factors have resulted in increased demand over the last few years. The first is an increasingly affluent society that demands more electricity year on year. South Africa has seen significant levels of growth in electricity consumption and the level of demand. There was 4.31% more energy consumed in 2007 than in 2006, as noted in figure 1. In addition to this growth in energy consumption, the growth in peak demand from 2006 to 2007 was 4.90% which equates to 1 706MW (DME, 2008).

Figure 1: 2006 vs. 2007 Week-on-Week Net Energy Sent Out



Source: DME, 2008

The second factor to affect electricity demand is the price of electricity. Electricity pricing contributes to high consumer demand as it is very low in South Africa compared to other countries around the world. Many countries have also embarked upon large build programmes and the gap between South Africa and the rest of the world is widening. The main issues regarding pricing are (DME, 2008):

• Current pricing is half of the replacement value of power plant
• Increases above inflation will be needed to fund capacity expansion

There is little indication whether the price increases have resulted in a decrease in demand for electricity. However, the improved financial performance will enable the utility to not only service its borrowings that were raised to fund multi-billion-rand capital expansion programmes (Njobeni, 2010).

2.2.2 Electricity Supply Constraints

The biggest immediate threat to South Africa's continued economic growth is an electricity capacity constraint that has arisen because of the country's strong economic performance in recent years. This growth has led to demand for electricity outstripping supply.

Eskom has been South Africa’s electricity public utility since 1923. It did not always carry this name. In 1987, ESCOM (Electricity Supply Commission) and EVKOM (Elektrisiteitsvoorsieningskommissie), the English and Afrikaans acronyms given to the business, were merged to form Eskom. The previous apartheid led government carried out a pattern of over-investment and contraction which led to there being times when South Africa had a large surplus capacity. As a result, South Africa offered (and still does) some of the lowest prices for electricity in the world (Eberhard, 2004). Eskom generates around two thirds of the electricity produced in the whole of Africa, and provides about 95% of South Africa's electrical power and more than 60% of Africa's. Generation is primarily coal-fired, but also includes a nuclear power station at Koeberg (1930MW), four gas turbine facilities (2400MW), two conventional hydroelectric plants (600MW), and two hydroelectric pumped-storage stations (1400MW). The company also owns and operates the national transmission system. Eskom has a nominal generating capacity of 44193 megawatts. Power from coal-fired generating plants amounts to 89% of Eskom's nominal generating capacity (Eskom, 2009).

South Africa has huge deposits of coal and its base-load stations are mainly fired by coal. South Africa produces an average of 224 million tonnes of marketable coal annually, making it the fifth largest coal producing country in the world. 25% of that production is exported internationally, making South Africa the third largest coal exporting country. The remainder of South Africa's coal production feeds the various local industries, with 53% used for electricity generation. The key role played by those coal reserves in the economy is illustrated by the fact that Eskom is the 7th largest electricity generator in the world. Eskom (2009) estimate South Africa's coal reserves at 53 billion tonnes and at present production rate there should be almost 200 years of coal supply left. According to the 2010 BP Statistical Energy Survey (2010), South Africa had coal reserves of 30 billion tonnes at the end of 2009, 3.68% of the world total. South Africa has Africa's only significant coal reserves. 20 billion tonnes is a large disparity between two studies and this is evident in many others carried out on South African coal reserves. However, the amount is still large and will continue to dictate Eskom's way of generating electricity.

In terms of non-thermal generation, the country has limited hydro-electric resources and Koeberg, commissioned in 1984, is South Africa's only nuclear installation. This 1 930 MW station is located near to the major load centre of Cape Town, at the opposite end of the country from the coal reserves of Mpumalanga (Eskom, 2009).

When the democratic revolution came about in 1994, the ANC-led government looked to implement a number of reforms to the electricity industry. The ANC looked to consolidate electricity distributors, improve the efficiency of Eskom and to create an industry structure that allocated risk in a manner that encouraged investment efficiency (Eberhard et al, 2001).

By 1998, the government had produced the White Paper on Energy Policy, which predicted that South Africa would run out of electricity in 2007. This prediction was very much in line with what Eskom was saying the time. The White Paper suggested that to sustain supply to South Africa, new investment in generation capacity would have to be made by the end of 1999 (Centre for Development and Enterprise, 2008).

This new investment never happened. Instead, in response to the reforms put forward earlier, the government looked to introduce a competitive electricity market, with the aim of increasing investment from the private sector and taking the financial burden away from the government. This process, which took place between 2001 and 2004, also signalled a period when the government put a temporary ban on Eskom from building any new generation plants (Centre for Development and Enterprise, 2008). The government struggled to create a secure market structure and therefore a competitive electricity market never materialized.

The failure of this process which led to the moratorium on the building of generation plants and a lack of investment from the private sector led to South Africa experiencing an electricity crisis in 2008. From November 2007 to January 2008 South Africans encountered a high number of power outages, culminating on the 25th of January 2008 when Eskom, South Africa's electricity public utility, declared force majeure and requested that the major mining groups shut down their operations or face a complete shutdown of all electricity supply. This electricity crisis left many people asking how Eskom allowed the situation to deteriorate to such an extent and also how there seemed no contingency in place to deal with such an incident (Centre for Development and Enterprise, 2008).

In 2002, the generation reserve margin was 25%. By 2006 it had dropped to 16% and in 2008 it was 8%. For a utility to be able to carry planned maintenance and unplanned breakdowns, the reserve margin should be at least 20% (NERSA, 2008). With no new generation plants commissioned after 2001, a lack of maintenance and with the forecasts set towards an eventual breakdown in supply, it comes as no surprise that Eskom struggled to keep its plants running at sufficient output.

Some argue that these were not the only reasons that Eskom failed in its electricity supply. The National Energy Regulator of South Africa (NERSA) carried out an inquiry into the crisis and found that the large amount of power outages was a result of low coal stockpiles and a high amount of rainfall in those areas where the coal is mined. This resulted in difficulties with the handling of the coal and due to the high rainfall the coal was less susceptible to burning. This lack of good coal meant that many power stations were unable to run at their full capacity. Coupled with the maintenance that needed to be carried out, these factors led Eskom to no other alternative but to initiate power outages (NERSA, 2008).

Up until March 2013, Eskom will spend R385 billion in nominal terms on capacity expansion. South Africa needs to build 40 000MW of new generation capacity by 2025, of which 12 476MW are already under construction (Eskom, 2009). The expansion is however targeting coal fired generation capacity, with Eskom largely leaving renewable expansion to Independent Power Producers (IPPs).

Ratings agencies Standard & Poor's and Fitch said in January 2008 that the electricity shortage was not seen as an immediate threat to SA's investment-grade credit rating, but could become an issue if it sharply curbed economic growth. However in November 2008 the country's outlook was changed from stable to negative as the financial crisis began to deepen. This rating has been at the same level since then. The rating has been further pressurised by concern over Eskom's ability to raise funds for its expansion programme and what would be a subsequent drop in its credit rating. This has been abated to some degree with the recent granting of a $3.75bn (R27bn) loan from the World Bank to build the Medupi power plant. However South Africa's rating will not be reviewed any time soon, leaving the outlook still relatively unstable (Business Report, 2010).

2.2.3 Increasing waste generation

The growth of South Africa has not only put a strain on electricity supply but also on waste management throughout the country. Consequently, over the last decade, waste management has been prioritised within environmental management as well as within the various governmental departments regulating those functions. Waste is not only a prominent issue in South Africa but is also one worldwide as shown by discussions at the 2009 World Summit on Sustainable Development (DEAT, 2009).

The increase in economic development has resulted in an increase in generation of commercial, industrial, hazardous, mining, power generation waste and radioactive waste. Each of these has to be regulated and managed under the National Environmental Management Act (NEMA), the Environment Conservation Act (ECA) and the National Water Act (NWA) (DEAT, 2009).

In 1998, total general waste from households, commerce, institutions and the manufacturing industry was approximately 13.5 – 15 million tonnes. This number has increased significantly over the last few years due to rising population and economic growth. Gauteng, followed by the Western Cape, generates the most waste per person at 760 kg/person/year. As provinces become more affluent and urbanised, larger amounts of waste are generated, increasing pressure on the infrastructure in place (DEAT, 2009).

In 2004/05, roughly 8.8 million tonnes of domestic waste required collection and disposal in South Africa. It has been estimated that growth since then has lead to the waste requiring collection and disposal to have risen to over 10 million tonnes and will continue to rise in the coming years. This has consequently begun to put a considerable amount of stress on local governments and service providers (DEAT, 2009).

Efforts have been made at a government level to streamline waste management activities in South Africa, thereby preparing the country for the continued rise in waste generation. The President of the South Africa signed The National Environmental Management: Waste Bill into an Act of Parliament in March 2009. This Act took effect from 01 July 2009 with the intention of addressing the fragmentation in waste legislation that is apparent in South Africa. Before this Act took effect, waste in South Africa, was governed by a number of pieces of legislation including (SAWIC, 2009):

- The South African Constitution (Act 108 of 1996)
- Hazardous Substances Act (Act 5 of 1973)
- Health Act (Act 63 of 1977)
- Environment Conservation Act (Act 73 of 1989)
- Occupational Health and Safety Act (Act 85 of 1993)
- National Water Act (Act 36 of 1998)
- The National Environmental Management Act (Act 107 of 1998)
- Municipal Structures Act (Act 117 of 1998)
- Municipal Systems Act (Act 32 of 2000)
- Mineral and Petroleum Resources Development Act (Act 28 of 2002)
- Air Quality Act (Act 39 of 2004)
- National Environmental Management: Waste Act, 2008 (Act 59 of 2008)

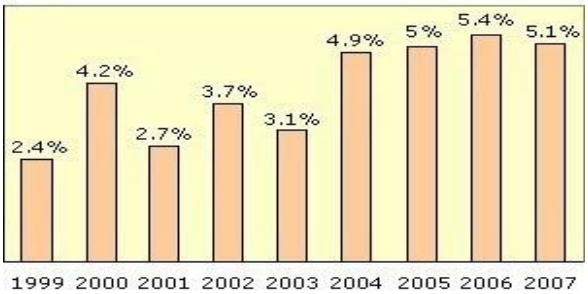
This new Act will help lead South African waste management into a period of increased protection of health and the environment by "providing reasonable measures for the prevention of pollution and ecological degradation and for securing ecologically sustainable development (Government Gazette, 2009)" and will " provide for specific waste management measures, provide for the licensing and control of waste management activities, provide for the national waste information system and provide for compliance and enforcement" (Government Gazette, 2009).

South Africa faces a number of issues when looking at waste management including:
lack of available or current waste information from all sectors; illegal dumping and illegal dump sites; use of unpermitted landfills by municipalities; large portions of the population not receiving a weekly or adequate waste collection service; waste minimisation which is almost exclusively industry driven; government departments' lack of waste databases; lack of regulation and enforcement of legislation and limited waste related legislation (DEAT, 2009).

<u>2.2.4 Population and economic growth</u>

From 1999 until the recent recession, South Africa's economy has been in an upward phase of the business cycle (Figure 2) - the longest period of economic expansion in the country's recorded history. During this upswing the country's annual economic growth rate has averaged over 4% (SouthAfrica.info, 2009).

Figure 2: GDP Growth in South Africa
Source: SouthAfrica.info, 2009



Human settlement dynamics such as population, commercial and industrial development, mining and agricultural activities affect the amount and type of waste generated. The main drivers for waste generation include the growth in population and increased economic development. Population growth results in an increased level of domestic waste and equally worrying an increase in health care risks from the generated waste. Economic development has an equivalent effect on industrial and hazardous waste generation (DEAT, 2009).

Table 2 shows how an increase in income levels is directly related to the average generation rate of waste in South Africa. From the 2001 census to the middle of 2004, the additional amount of waste generated equates approximately to 1.32 million tonnes or a 1.4% growth over 3 years. These increases have also meant that there has been an increase in the demand for service delivery, waste transportation and the increased maintenance of treatment and disposal facilities (DEAT, 2009).

Table 2: Income level vs. domestic waste generation rate
Source: Winkler, 2007

Income level	Average generation rate	
	(m^3/capita/annum)	(t/capita/annum)
High[1]	2,7	0,43
Medium[2]	0,75	0,17
Low[3]	0,24	0,08

Notes: Disposable income per annum:
[1] R10 000+
[2] R5 000 - R10 000
[3] R0 - R5 000

2.3 Is there a role for WtE in South Africa?

Thermal waste-to-energy technologies use heat or combustion to treat wastes. Incineration is the most widely used WtE thermal technology, but there are a number of other thermal technologies that are able to generate electricity from waste and other fuels without direct combustion. Many of these technologies have the potential for a greater energy output from the same amount of fuel than would be possible by direct combustion. These technologies include gasification and pyrolysis, both of which will be discussed in greater detail in Chapter 4.

A non-thermal process of WtE is one whereby methane and carbon dioxide rich biogas is produced that is suitable for energy recovery. This occurs when microorganisms break down biodegradable material in the absence of oxygen. An example of a non-thermal WtE process is anaerobic digestion, which will also be discussed in more detail in Chapter 4.

It has been shown that South Africa has an over reliance on coal for its energy requirements (refer to Section 2.2.1 and 2.2.2). South Africa has voluntarily opted to reduce its dependency on fossil fuels and promote renewable energy. At the 2009 United Nations Climate Change Conference, South Africa agreed to cut emissions by 34% below current expected levels by 2020. This is equivalent to an absolute emissions cut of about 18% below 1990 levels by 2020. To achieve this target, South Africa is going to have to accept an energy pathway that is not as dependent on fossil fuels (UNFCCC, 2010).

AGAMA (2006) highlighted the potential that WtE has in South Africa by analysing the following information: The six South African metros have disposed of a total 8.9 million tonnes of MSW on average per annum since 2004. The waste has a primary energy content of 71 000 TJ, a majority of which is simply discarded at South Africa's major landfills. Therefore Integrated Solid Waste Management that considers WtE could, and in essence should, make a contribution to the achievement of the renewable energy target set by government (AGAMA, 2006).

These findings show the opportunities that are available when assessing waste management combined with energy recovery. There is often apprehension attached to thermal WtE technologies in that they are just as harmful, and sometimes even more harmful, to the environment as fossil fuel burning. However there are also negative implications for the environment and human health that increasing MSW generation can have, such as continued air and land pollution and the pollution of fresh and marine waters, resulting in the disruption of ecosystem processes, habitat destruction and species loss. There is also the implication that increased waste generation has on the country's landfill sites. Many of these have a finite lifespan, and as waste generation increases, the space used to dispose of this waste will become less.

It is therefore important to address the impacts that WtE will have on MSW disposal and electricity generation if implemented by looking at both the good and bad of the thermal technologies. This is best shown by examining the experiences of regions that have implemented WtE technologies, including Europe and the United States.

There is a relatively small amount of coverage given to non-thermal processes as they are seen as a smaller-scale solution to waste problems. However there is evidence to support non-thermal technologies at a larger municipal level, although there are also negative implications associated with this. The pros and cons of thermal and non-thermal WtE technologies will be addressed in the following section.

2.4 The Pros and Cons of Thermal and Non-thermal Waste-to-Energy Technologies

This section will look more closely at the pros and cons of thermal and non-thermal WtE technologies, highlighting the experiences of other countries that have had dealings with WtE facilities. This will help provide further explanations on the applicability of WtE in South Africa.

2.4.1 Thermal Waste-to-Energy Technologies - Pros

1. *Decreases GHG Emissions by Diverting Waste from Landfill*

   WtE has a positive influence on the amount of waste that is diverted from landfills. Methane production from MSW landfills worldwide is thought to represent between 5% and 15% of total methane atmospheric emissions. Methane is 20 to 25 times more effective on a molar basis than carbon dioxide at infrared energy absorption, contributing significantly to the greenhouse effect. Usually, gas production begins within a year of waste placement and may continue for as long as 50 years after landfill closure (Cooper, 1992).

   Comparative studies of WTE and landfilling have shown that for each ton of MSW combusted, rather than landfilled, the overall carbon dioxide reduction can be as high as 1.3 tons of CO_2 per ton of MSW when both the avoided landfill emissions and the avoided use of fossil fuel are taken into account. Furthermore, by using MSW instead of fossil fuels to produce energy results in fewer greenhouse gas emissions (Bhada, 2007).

2. *Reduction in use of non-renewable resources*

A government and active private sector that invests in WtE can have a meaningful impact in reducing a country's dependence on fossil fuels. This is especially important in South Africa, whose dependence on fossil fuel burning for electricity generation continues to create problems of inconsistent supply and climate change implications. MSW is comprised of roughly 56% biogenic and 44% non-biogenic materials. Every ton of MSW processed in a WTE facility avoids the mining of one third ton of coal (ASME, 2009). This also impacts GHG emissions that would have resulted from the burning of traditional fossil fuels.

3. Complements recycling

Many argue that incorporating WtE into cities' Integrated Waste Management Programme will significantly undermine recycling programmes that are already in place. However, WtE is actually seen as compatible with recycling rather than a hindrance to the process.

For instance, it has been shown that WtE plants have fewer instances of operational and maintenance problems when non-burnable recyclables are diverted away from the facilities. Also WtE provides a short term management option when recycling markets are not available or well-enough established. Recycling and WtE also work in partnership to help reduce landfilling and thereby reduce GHG emissions. By recycling materials with higher calorific content such as paper and plastic, the overall heating value of the waste is reduced which results in more efficient plant operation. Also by recycling glass, metals and other non-combustible recyclables, the MSW fuel characteristic at WtE operations are improved. It has been shown that by installing a WtE facility, the surrounding areas tend to have a higher than average recycling rate than those areas without a WtE facility (Kiser, 2003).

4. Materials Recovery

Another beneficial effect of modern MSW combustion with energy recovery is material recovery. If correct waste management infrastructure is put in place along with thermal technologies, specifically material recovery facilities (MRFs), a large amount of valuable materials can be reclaimed before combustion of MSW takes place. MRFs separate out valuable resources from MSW so that feedstock is prepared for combustion and is of the highest calorific quality. This preparation of feedstock includes recovering bulky items, cardboard, glass, aluminium cans, tin cans and other ferrous materials. The remaining ash can be utilised in the construction and maintenance of landfills and as an aggregate in construction (Nemerow et al, 2009).

2.4.2 Thermal Waste-to-Energy Technologies - Cons

1. *Emissions from WtE facilities*

Many WtE facilities incorporate a combustion process to deal with the MSW. It is this combustion that makes WtE a contentious technology as many feel that the emission released through combustion processes are as harmful, if not more so, than those used in traditional coal fired plants. Emissions of Particular Matter (PM), mercury, hydrochloric acid and dioxins have been highlighted as the main concern from many stakeholders. However, advancements in technology have meant that modern WtE facilities have had emissions reduced considerably. This has happened through the reduction of precursors in the feed (e.g. mercury containing products), improved combustion practices and greatly improved gas control systems that include dry scrubbing, activated carbon injection and filter bag collection systems (Estevez-Weinstein, 2006).

Table 3 and table 4 below show the percentage decrease in emissions from WtE facilities within a decade for the United States and Germany respectively. In the year 2000 roughly 26 million tons of MSW were sent to WtE facilities in the United States annually (Themelis & Millrath, 2004). In Germany, the waste incineration capacity increased from 9 million tons in 1990 to 14 million tons in 2000 (Stengler, 2005). This occurred even with a decrease in emissions across the board.

Table 5 highlights the difference in emissions per unit of heating value from coal fired power and WtE in the United States. Emissions of sulphur dioxide, nitrogen oxides and cadmium are lower in WtE facilities than coal fired plants. Conversely, emissions of hydrogen chloride, lead and mercury are higher in WtE plants than coal fired plants. This remains a stumbling block to an increase in the acceptability of WtE facilities, even though efforts are being made to reduce these figures.

Table 3: Emission reductions from WtE facilities between 1990 & 2000 in the US
Source: Themelis & Millrath, 2004

Pollutant	Reduction (%)
Dioxins/Furans	99.7
Mercury	95.1
Cadmium	93.0
Lead	90.9
Particulate matter	89.8
Sulfur dioxide	86.7

Table 4: Reductions from WtE facilities between 1990 and 2001 in Germany
Source: Stengler, 2005

Pollutant	Reduction (%)
Mercury	98.7
Lead	99.8
Particulate matter	<88

Table 5: Emissions per unit of heating value of plants in the US (kg/GJ)
Source: Themelis & Millrath, 2004

	Coal-fired plants	WTE facilities
Sulfur dioxide	0.452	0.013
Nitrogen oxides	0.194	0.151
Hydrogen chloride	0.017	0.087
Particulate matter	0.03	0.002
Lead	$2.6 * 10^{-6}$	$15 * 10^{-6}$
Mercury	$2.6 * 10^{-6}$	$7 * 10^{-6}$
Cadmium	$1.9 * 10^{-6}$	$1.1 * 10^{-6}$

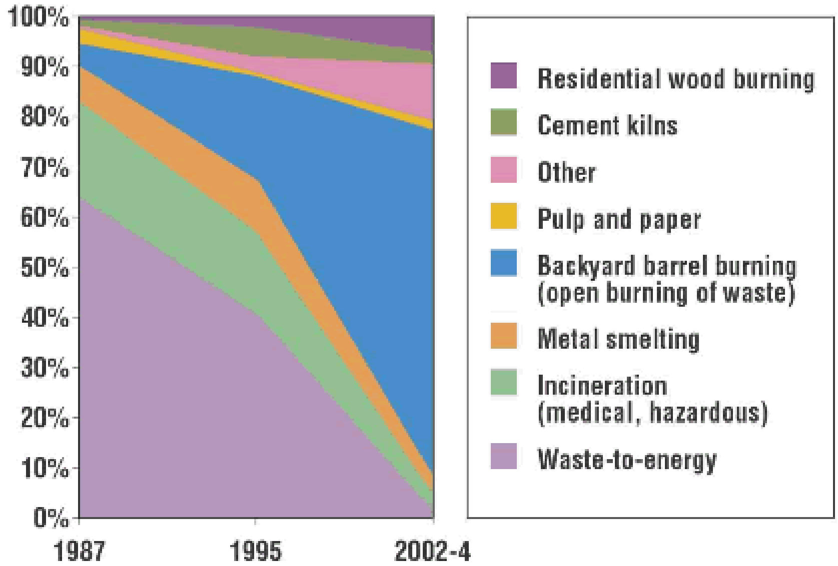
Greenpeace (2010) has argued that the process of incineration is still not environmentally safe and is still responsible for releasing metals that are not destroyed during the incineration process. Also the metals that are released are in a more concentrated and dangerous form of particulates exposing people to inhalation risks. This is shown in the figures in table 5 above. Although pollution control equipment has advanced, not all heavy metals are removed and are merely transferred to stack gases and ash. This ash may leach into the soil when disposed of and cause contamination of water bodies.

These are all issues that should be addressed by any WtE facility and it is now common place for emission testing to take place at regular intervals. The advancement in air quality control policies and regulations has led to WtE becoming 'cleaner'. However it has yet to become completely emission free and until this happens, environmentalists will continue to question the long-term acceptability of the thermal WtE technologies as a solution to the problem of waste.

Greenpeace (2010) has also given much coverage to the emission of dioxins from WtE facilities. Dioxins are a group of compounds that have similar chemical characteristics. Approximately 30 compounds fall into three groups: chlorinated dibenzo-*p*-dioxins (CDDs), chlorinated dibenzofurans (CDFs) and some polychlorinated biphenyls (PCBs). The term 'dioxin' is also used to refer to one of the most toxic of these compounds, 2,3,7,8- tetrachlorodibenzo-*p*-dioxin (TCDD). The toxicity of dioxins is measured in terms of Toxic Equivalents or TEQs, which is the equivalent amount of TCDD in a mixture of dioxin compounds. Dioxins are carcinogenic and lipophilic, which means that they can easily dissolve in fats, oils, and lipids, and hence accumulate in humans and wildlife, causing significant concern about the risks associated with them. Dioxins can be found in the air, soil and food. Only a small amount exposure is from the air: eating contaminated foods in the primary source of exposure (EPA, 2008).

According to the United States Environmental Protection Agency, the main sources of dioxins are coal-fired plants, metal smelting plants, diesel trucks, and waste burning. However from 1987 to 2007 dioxin emissions from waste-to-energy facilities in the US decreased from 10,000 g/year to 12 g/year. At present, dioxins from waste incineration constitute less than 0.05% (Figure 3) of the total US inventory. In many cases, the stack gas from WtE facilities is found to be cleaner than the ambient air in some US cities. If one looks at the case of Germany, it is estimated that residential fireplaces emit 20 times more dioxins than do the most modern WTE facilities in Germany (Bhada, 2007).

Figure 3: The distribution of dioxin sources in the US in recent years, showing how WtE ceased to be a major contributor of dioxin emissions
Source: Themelis, 2003



2. Ash disposal

Another challenge that WtE faces is the disposal of ash that is a result of the combustion process. Ash can contain high concentrations of various metals that were present in the original MSW. Textile dyes, printing inks, and ceramics, for example, contain the metals lead and cadmium. Separating waste before combustion can solve part of the problem.

If the incinerator is operating correctly, the residue or ash should be completely burnt out and biologically sterile. Bottom ash from the furnace grate represents the bulk of total ash and is composed mainly of mineral oxides. The high heavy metal concentrations present in the ash residues form incineration become of more significance when they are placed in landfill sites, where leaching of pollutants can cause groundwater contamination. There are however other treatment methods used or under investigation to stabilise combustion ash. These include chemical stabilisation, ash melting and extraction/recovery processes. The ash can be used with cement ti produce a low permeability product that can bereused as roadbed material or road aggregate (Williams, 2005).

3. Lack of versatility

Many thermal waste-to-energy technologies are designed to handle only one or a few types of MSW (whether plastic, biomass, or others). However, it is often impossible or cost-prohibitive to fully separate different types of waste or to determine the exact composition of a waste source. For many waste-to-energy technologies to be successful, it will be required that they become more versatile or are supplemented by material handling and sorting systems (Raje, 2007).

4. High Capital Costs

Thermal WtE systems are often expensive to install. Despite the financial benefits they promise due to reductions in waste and production of energy and other revenue streams created, putting together the financing packages for installations often provides a major hurdle to implementation. This is especially true for new technologies that aren't widely established and therefore not readily accepted in the market place (Raje, 2007).

2.4.3 Non - Thermal Waste-to-Energy Technologies – Pros

1. No burning

Non-thermal WtE technologies are rapidly becoming more advanced and many waste management strategists are beginning to see the value in using non-thermal technologies. One of the major pros with regards to non-thermal technologies is that they are just that – non thermal. They do not encounter many of the problems that thermal WtE technologies encounter, with regards to emissions, ash creation and dioxin problems that come about as a result of burning. Instead, non-thermal technologies are much cleaner and environmentally friendlier than their thermal counterparts.

2. Reduces Organic Waste at Landfill

Non-thermal technologies mainly deal with organic waste that is suitable for biological treatment. Therefore any organic waste that ends up at a non-thermal treatment plant is not going to landfill and the subsequent emissions that would have been generated are avoided (see point 1 under section 2.3.1). This also aids in reducing landfill size and the amount of organic waste that would be found at a landfill site. The nature of the technologies means that the processes take place within a closed system, once again ensuring that emissions are avoided.

3. Complements Recycling

Non-thermal WtE technologies can also improve the effectiveness of recycling activities if the relevant recycling systems are successfully implemented. If MSW that goes to landfill or a non-thermal site is to be processed then it must be sorted so that only organic materials are present in the feedstock. This means that the remaining material will not have organic waste present and will make the recovery of recyclables potentially easier.

4. Energy Potential from Non-thermal Waste-to-Energy technologies

The potential energy production from non-thermal WtE technologies is vast. Table 6 shows the energy benefits that could be realised if one were to treat waste water or organic waste. A theoretical total of 207MW is significant when one considers that one unit at the Ankerlig Gas Power Station has a capacity of 148MW. This facility requires 1300 – 1400 litres of fuel per minute when in operation (Eskom, 2009). These facilities form an integral part of South Africa's electricity supply, and are often responsible for additions to peak load generation. This theoretical estimate considers the treatment of organic waste and waste water in South Africa (AGAMA, 2009).

The realistic total is lower at 56MW. This is because for these calculations, a 25% capture fraction of organic waste and waste water was considered. To capture all organic waste for treatment may be ambitious, and therefore a more reserved estimate is used to obtain the realistic total. This does however still represent a large amount of electricity and also a significant amount of organic waste that would be treated (AGAMA, 2009).

Table 6: Summary of South African electrical energy potential from wastewater and organic waste
Source: AGAMA, 2009

Waste	Electrical Capacity	Electrical Generation
Theoretical		
AD of wastewater	31 MW	263 GWh/a
AD of organic solid waste	176 MW	1,500 GWh/a
TOTAL	**207 MW**	**1,763 GWh/a**
Realistic		
AD of wastewater	12 MW	105 GWh/a
AD of organic solid waste	44 MW	375 GWh/a
TOTAL	**56 MW**	**480 GWh/a**

2.4.4 Non - Thermal Waste-to-Energy Technologies – Cons

1. Lack of large scale implementation in developing countries

Anearobic digestion of sewage sludge and agricultural waste is a well established technology, although less so for the biodegradable fraction of MSW. However it has been estimated that worldwide there are more than 125 anaerobic digestion plants treating biodegradable MSW. In Europe, Denmark, Germany, Italy, the Netherlands and Sweden have fully developed anaerobic digestion plants for handling organic wastes. Significant and successful anaerobic digestion sites include Tilburg in the Netherlands and Barcelona's Ecopark II, both of which are discussed later in the thesis. Even though this provides evidence of implementation in Europe, there are to date very few non-thermal AD sites in developing countries that treat large amounts of organic waste found in MSW (Williams, 2005).

2. Odour & emissions

Non-thermal technologies yield a reduced volume of sludge which yields odour problems. Biogas produced through non thermal processes usually consists of CO_2, CH_4, N_2 and H_2S and occasionally traces of H_2. Because water waste and effluent is commonly used in the biological treatment plants, it is imperative that bio reactors and the associated handling facilities are designed so that odours and emissions of harmful gases are managed and/or minimized (IPPTS, 2010).

2.5 Conclusion

South Africa is entering a period where continued economic prosperity and growth will be largely dependent on whether it can address the current issues that it is encountering with energy supply. Coupled with this, are the new directives that many municipalities will be following to deal with ever increasing municipal solid waste efficiently and safely.

Waste to Energy technologies, although not without concerns, can provide the national and local governments with a means of dealing with two problems at once: decrease waste and create renewable energy.

The following section will provide a detailed description of what integrated solid waste management is and look more closely at the solid waste management sector in Cape Town. This will help put into perspective the situation that Cape Town finds itself in and how WtE could prove to be a positive addition to the City's integrated waste management programme.

Chapter 3: Overview of Integrated Solid Waste Management in Cape Town

3.1 Background

The City of Cape Town (Figure 4) is the second-most populous city in South Africa, and the largest in land area. It forms part of the City of Cape Town metropolitan municipality and is the provincial capital city of the Western Cape. It also serves as the legislative capital of South Africa, where the National Parliament and many government offices are situated.

In 2007, the City of Cape Town had a population of 3.5 million people. Cape Town's land area of 2,455 square kilometres is larger than other South African cities, resulting in a comparatively lower population density of 1,425 inhabitants per square kilometre (CoCT, 2010).

Figure 4: City of Cape Town
Source: About Cape Town, 2010

Being the centre for commerce and industry for the Western Cape and due to its growing reputation as an attractive destination for both domestic and international tourists, Cape Town has experienced intense movement of people, goods and services, and extensive development of multiple business districts and industrial areas in recent years (Tsekoa,et al, 2007)

Before the merging of the local government structure into a 'Unicity', Cape Town was administered on the basis of six administrative areas, namely Blaauberg, Cape Town CBD, Helderberg, Oostenberg, South Peninsula and Tygerberg.

The details of the main suburbs within these areas are (Tsekoa et al, 2007):

- Blaauwberg: Milnerton, Tableview and Bloubergstrand.
- Cape Town Commercial Business District: City Bowl, the Atlantic seaboard, southern suburbs, Pinelands, Langa and Mitchell's Plain.
- Helderberg: Somerset West, Strand and Gordon's Bay.
- Oostenberg: Kraaifontein, Brackenfell, Kuilsrivier, Blue Downs and Eerste River.
- South Peninsula: Hout Bay, Wynberg, Constania, Fish Hoek, Kommetjie, Noordhoek and Simon's Town
- Tygerberg:Tygerberg, Durbanville, Bellvile and Khayelitsha

The commercial activities, the city's growing attractiveness as a tourist destination and the boom in real estate have resulted in a great boost for the local economy and also contribute to the country's GDP (Tsekoa et al, 2007). This has also started to create strain on the public services provided in Cape Town, resulting in planned investment in service delivery and landfill sites in the coming years to make sure that the extra capacity can be catered for.

This chapter gives a detailed description of what integrated solid waste management is. It will also look more closely at the solid waste management sector in Cape Town and the City's current integrated waste management process as well as the initiatives that the City is trying to implement to improve waste management practices. Information on waste generation, disposal, characteristics of waste, waste collection and recycling is not as important to this study as the areas mentioned, but are given coverage in appendixes A to F.

3.2 What is Integrated Solid Waste Management (ISWM)?

"Integrated pollution and waste management is a holistic and integrated system and process of management, aimed at pollution prevention and minimisation at source, managing the impact of pollution and waste on the receiving environment and remediating damaged environments."
(DEAT, 2000)

As waste management issues gain public awareness, concern has risen about the appropriateness of various disposal methods. Within our modern scheme of waste management, disposal is the last phase. Most people acknowledge that disposal will always be needed (the exception being those advocating zero-waste policies). An effective ISWM system considers how to prevent, recycle, and manage solid waste in ways that will most effectively protect human health and the environment and subsequently reduce stress on disposal systems. ISWM involves assessing specific local needs and conditions, and then choose and combine the most appropriate waste management activities to suit those conditions. The major ISWM activities are: reduction, reuse, and recovery before disposal (EPA, 2002).

Figure 5: Hierarchy of Integrated Solid Waste Management
Source: Heimlich et al, 2005

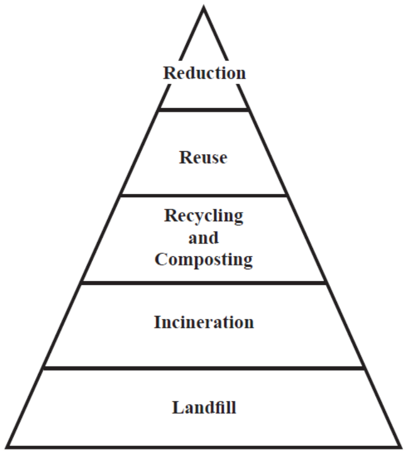


Figure 5 shows that there are a number of strategies for change:

3.2.1 Reduction Strategies

Reduction strategies are any approaches a community can use to decrease the amount of waste being produced. Examples of reduction strategies include a surcharge on excess bags, containers, or household refuse or an incentive program for commercial/ industrial reduction efforts. A simple reduction activity that individuals within a community can do is two-sided copying on paper. A waste exchange program also contributes to reduction. Reduction, combined with education efforts on the part of local municipalities, does however assume the commitment and involvement of all citizens. Source reduction strategies can have a number of favourable environmental impacts, including reducing greenhouse gas production, saving energy, and conserving resources, in addition to reducing the volume of the waste stream (Heimlich et al, 2005).

Businesses can also benefit from reduction campaigns as it can helps industries decrease raw material use and cut manufacturing costs. An example of waste reduction in industry is the mobile phone sector. Current wireless devices (e.g., cell phones) weigh approximately 79g, 42% less than earlier models. Manufacturers are maximizing the use of recycled materials, and phasing out the use of cables containing lead, cadmium, and PVC from decorative parts of the wireless device-all toxic materials. This provides a prime example of what a well implemented reduction strategy can achieve (KAB, 2006).

3.2.2 Reuse Strategies

Reuse is using a product more than once, either for the same purpose or for an alternate purpose. Reuse does not require reprocessing and, therefore, has lower energy requirements than recycling. Reuse strategies include making donations to charity, reusing packaging (including boxes and bags) and using empty jars for food storage (Heimlich et al, 2005).

Hirschorn (1993) argues that it is imperative for industry and commerce to also initiate reuse strategies as materials play such an important role in the production of goods and services. Industry must make the point of realising that if a product or material can not be reused, it could be sold on and used by another industry for a different purpose.

3.2.3 Recycling and Composting

In recycling, waste materials are reprocessed and reformed into new or similar products. Recycling includes pre-consumer waste, such as factory cuttings or shavings, as well as post-consumer waste items, including cardboard, newspapers, plastic bottles, and aluminium cans.

It almost always takes less energy to make a product from recycled materials than it does to make it from new materials. An example of this is the case of aluminium. Scrap aluminium can be used to make new aluminium cans and by doing so uses up to 95% less energy than making cans from bauxite ore, the raw material used to make aluminium. This figure may not be as high for all recyclable products, but is recurrent through many products (EIA, 2010).

There is still some debate over whether recycling is economically efficient for municipalities and local governments. Municipalities can often see fiscal benefits from implementing recycling programs, as there is less waste being sent to landfill. However the infrastructure needed to implement a sustainable recycling programme can often be costly. If recycling is seen as a strategy for waste management going forward, then all financial costs and benefits must be investigated.

Composting can be used to treat both the organic fraction and the paper fraction of an MSW stream. Carbon dioxide and water are released into the atmosphere, while minerals and organic matter are converted into a potentially reusable soil-like material – compost (Daskalopoulos et al, 1998). The significant volume reductions associated with composting and the possible uses of compost (namely as a benefit to nutrient deficient soils) make MSW composting attractive as a potential means of diverting waste from landfills (Renkow, 1998).

3.2.4 Incineration/Energy Recovery

The incineration of waste aids in recapturing value by using the heat generated for energy purposes. Although many combustibles are recyclable, there is often a higher total value in burning the waste for energy than in recycling (due to processing costs). In many situations combustible/recyclable materials are contaminated and rendered difficult and/or expensive to recycle. By developing an incineration program with a materials recovery component, furnace and processing equipment life is usually extended because glass and ferrous and non-ferrous metals are removed during material recovery. Incineration reduces the volume of refuse by up to 90 percent, leaving behind only ash, and resulting in less need for landfill space (EPA, 2002).

3.2.5 Landfill

The last option on the hierarchy is disposal. Given current technology, there are residuals from the previous processes, and some materials are simply not recoverable and must go somewhere.
The continuing development of more stringent requirements for landfills is making this option less environmentally prohibitive, but more costly. The increasing ability to recover methane from landfills provides a positive use for what has historically been a non-valued disposal method (Heimlich, 2005).

An integrated waste management system entails a careful analysis of what is in the waste stream and offers ideas on practices to recover the various materials at the point of highest value. The best strategy for any city or municipal district is to match its unique position with the optimal mix of activities that will best serve the area now and in the future.

3.3 ISWM in Cape Town

In 2006, Cape Town's Integrated Waste Management (IWM) policy was adopted and consequently the Solid Waste Department now has a mandate concentrating on preventing pollution and waste at source rather than focusing on treatment and disposal of waste once it has been generated (CoCT, 2010).

The Solid Waste Department has come to acknowledge the economic value of waste and has looked to implement policy that helps encourage recycling and reuse. This leads to a minimisation of health, socio-economic and resource impacts and thereby reduces the amount of waste that ends up at the ever decreasing landfills in and around the City. During the 2006/07 financial year, 14% of waste was diverted from landfill sites and was either reused or recycled. This gives a good indication that the people of Cape Town have begun to implement minimisation strategies that have been suggested. The waste that was diverted includes builder's rubble, glass, paper and plastic (CoCT, 2010).

The aim of the City of Cape Town's Solid Waste Management Department is to (CoCT, 2010):

- Ensure that efficient and effective basic waste management services are accessible and available
- Maintain acceptable cleanliness standards
- Promote and ensure waste minimisation
- Reduce the impact of waste

The department's main functions include waste collection, area cleaning and waste disposal. Each of these functions is carried out within Cape Town's social, economic, health and legislative obligations and works very much in conjunction with Environmental Resource Management, Water and Sanitation Services, Planning and Building Development Management, Health, Economic and Human Development, Tourism and Integrated Development Planning (CoCT, 2010).

The following points highlight the purpose of the ISWM policy for Cape Town (CoCT, 2006):

- Integrate and replace outdated Council policies that will simplify and standardize the provision of waste management services;
- Align the Council's waste management services with the National Waste Management Strategy (NWMS) and the White Paper on Integrated Pollution and Waste Management (National Policy) as a means of minimizing waste generation and disposal within the City's boundaries;
- Provide a basis for an integrated by-law that will be used to regulate waste generation and waste management services, as well as serve as a disincentive where necessary;
- Introduce, facilitate and encourage effective waste minimisation and waste management practices, as per the NWMS Waste Management Hierarchy:
  1. Reuse waste in its original form as far as possible;

2. Promote the separation of waste into different streams at source prior to collection for recovery and recycling purposes;
3. Implement waste diversion away from landfill by ensuring that appropriate mechanisms and legalised facilities are in place through relevant permitting or applications;
4. Facilitate the processing or treatment of any recyclable waste in an economical and environmentally-sustainable manner;
5. Enable enterprises involved in the recycling of waste materials;
6. Advocate the reuse of waste materials as far as possible;
7. Dispose the remaining waste responsibly by utilising processes and methods that will conserve air space to lengthen the life of landfill sites, and methods that will impact minimally on water, ground water, soil or air.

- Ensure the effective and economical long term provision of waste management solutions for the City, supported by a sustainable and economically viable funding strategy.
- The Integrated Waste Management Policy is to be linked directly to the City's Integrated Waste Management Plan, which serves as the vehicle for the implementation of the Policy in terms of the City's Integrated Development Plan (IDP).

The ISWM Policy has the intention of being flexible and yet robust with a long-term horizon of twenty to thirty years which links in with timeframes established in the NWMS. There has however been a margin left open in case national policy or legislation that guide the IWM policy are amended, thereby allowing the IWM policy to be reviewed as soon as national changes have been introduced (CoCT, 2006).

3.4 Current Plan for Solid Waste Management in Cape Town

3.4.1 Integrated Waste Management by-law

The City of Cape Town is the first municipality in the country to introduce a new waste management by-law in line with new national legislation. This new by-law will regulate recovery and recycling activities apart from the usual waste activities, and set down minimum requirements for waste storage and infrastructure. It was presented to Council on Monday, 30 March 2009, and was forwarded to the Provincial Government for promulgation (Pollack, 2009).

The new by-law is aimed at regulating and controlling the management of waste within the city of Cape Town. It replaces old by-laws, thus ensuring a uniform approach to waste management throughout the city. It is also closely aligned with the National Waste Management Strategy, as well as the National Environmental Management: Waste Act 59, which was gazetted on 10 March 2009. Importantly the by-law is underpinned by the City's Integrated Waste Management Policy adopted in 2006 (Pollack, 2009).

In terms of the new national legislation, "municipalities will regulate all entities that provide waste management services or generate waste. Accreditation will be required to ensure that all service providers abide by the City's by-laws and general environmental legislation (Pollack, 2009)".

There is also provision for the separation of waste that has value and can be recycled. The by-law spells out the City's rights regarding waste management services, and its obligations regarding cleaning and cleansing, the responsible disposal of waste that cannot be recovered for recycling; collection and recovery for recycling, and the processing and treatment of waste and recyclable materials (Pollack, 2009).

3.4.2 Section 78.3 Process

The City Council recently set in motion the Section 78.3 process. This is a clause from the Municipal System's Act, wherein Council needs to consider alternative service provision if they cannot render those services themselves. This brings potential assistance from external sources into the mix. All options must be considered including waste-to-energy. It has been made abundantly clear that Alternate Service Delivery does not mean that the City's Solid Waste Management Department will be privatised. It does however mean making significant changes in terms of the system and infrastructure to give effect to minimising waste and its effects by considering alternate methods or technologies (Coetzee, 2009).

The key drivers for the investigation are:

1. National Environmental Management Waste Act (59 of 2008).
2. National Waste Management Strategy.
3. City of Cape Town IWM Policy.
4. City of Cape Town IWM Plan (Sector Plan).
5. City of Cape Town IWM By-law.
6. Council resolution MC24/03/08: authorising MSA S.78(3) assessment.

The current state of the waste management system is also seen as a major reason for this process. With 3 New Integrated Transfer Stations planned and recycling at about 17% by volume consisting of mainly organics (chipping & composting), builder's rubble and packaging (plastics, paper, glass, metal), services need a major adjustment in technology, mechanisms & waste management systems (Coetzee, 2009).

The key waste minimisation and efficiency initiatives that are to be addressed include (Coetzee, 2009):

- Integrated Transfer Stations and auxiliary facilities (MRF's, processing, etc);
    1. Transfer by rail (Transnet's non-preferred business);
    2. Collection & haulage to transfer stations.
- Drop-off Facilities;
- Green Waste;
- Builder's/Demolition Rubble;
- New Landfill;
- Residential recycling (Split bag, other alternatives)
- Job creation, SMME's, NGO's, etc
- Household hazardous waste
- Area Cleaning
- Recycling in public areas
- Fleet and workshops;
- Waste-to-Energy
- Landfill gas management (excluded: awaiting results of feasibility assessment, report and recommendations from CEF regarding a way forward)
- Implementation of the City's new IWM By-law: Governance, support and regulation

3.5 Conclusion

This chapter has given an account of the measures needed to create and implement a successful integrated waste management programme. By following the hierarchy of integrated solid waste management, a municipality has the ability to look at its own situation and apply the best mix of activities and services that will serve its area best going forward.

The City of Cape Town is currently experimenting with this mix, looking at the best ways to encourage reuse of waste, recycling and other measures to minimise waste that ends up at the increasingly pressured landfill sites around the City. The City is also working hard with the private sector to introduce and offer services that it feels it cannot properly implement due to budgetary or personnel constraints. This openness to work with businesses that will provide these services will provide the strength and future growth that the City knows it needs without compromising its own long-term strategies.

At the same time, measures are being taken to investigate other options that the City could implement, providing they are sustainable, affordable and in Cape Town's best interest. The possibility of putting WtE into practice forms part of this investigation and the City is open to any number of options, providing they meet the required criteria.

The following chapter will look closely at non-thermal and thermal WtE technologies and the pathways for municipal solid waste. The processes of various technologies will be scrutinised and debated, as well as case studies that will highlight the successes and possible pitfalls associated with these technologies. This will provide a technical background and the knowledge required to understand how WtE processes work and under what conditions this will occur optimally.

This will be followed by an introduction to the pathways for MSW, looking closely at how WtE can successfully be implemented into an integrated waste management programme and the infrastructure required to achieve this.

Chapter 4: Non-thermal and Thermal Waste to Energy Technologies

4.1 Background

Waste-to-energy has been recognized by the U.S. Environmental Protection Agency (EPA) as a clean, reliable, renewable source of energy (EPA, 2010). Municipal waste treatment technologies that are appropriate should be selected based on factors including characteristics of the waste generated the economic viability of the technology and the environmental and social impact of the technology. These technologies can be divided into two broad categories: non-thermal and thermal. Thermal technologies include incineration, gasification, and pyrolysis. The thermal technologies mentioned above will all be discussed in some detail, but the two main processes that will be investigated for the purposes of this study are incineration and gasification.

Non-thermal technologies include fermentation, composting and landfill-gas-to-electricity. For the purposes of this thesis, anaerobic digestion will be the focus of the non-thermal study. Excluding certain technologies does not negate their potential. The eThekwini Metropolitan Municipality is currently running a successful landfill-gas-to-electricity facility (Sustainable Energy Africa, 2009:3). The reason for selecting the above mentioned technologies for investigation is that they all contribute to decreasing the amount of waste that would be disposed of at landfill, in alignment with the hierarchy of integrated solid waste management.

This chapter will look more closely at the technologies mentioned above, giving detailed explanations of processes, optimal operating conditions, various outputs and the notable benefits and problems of each technology. There will also be case studies that highlight where specific technologies have been implemented successfully, under what conditions and why they continue to be a success.

These technology descriptions will be followed by a background to the pathways for municipal solid waste and how waste-to-energy technologies can form an integral part of a City's integrated waste management programme. This will also include explanations of the non – WtE elements of the study.

4.2 Thermal Technologies

4.2.1 Incineration

The most common WtE implementation in current circulation is the combustion of organic material such as municipal waste, known as incineration, with energy recovery. There is much concern at both a governmental and public level about the environmental impacts of incineration. However much of this concern is linked to early incineration technology. Modern incineration systems use high temperatures, controlled air, and excellent mixing to change the chemical, physical, or biological character or composition of waste materials. The new systems are equipped with state-of-the-art air pollution control devices to capture particulate and gaseous emission contaminates.

The heat produced by an incinerator can be used to generate steam which may then be used to drive a turbine in order to produce electricity. The way that the waste is incinerated is dependent on the pre-treatment that the municipal waste. Mass burning occurs when the MSW is unprocessed while Refuse Derived Fuel (RDF) burning takes place when the MSW is processed (Kumar, 2000).

Mass Burning

Mass burning is the most common technology wherein MSW is burned without significant preparation. The limited processing that does take place is to remove over-sized items that may threaten the integrity of the equipment. An incinerator may be divided into five main areas: 2aste delivery, bunker and feeding system; furnace; heat recovery; emissions control; energy recovery via district heating and electricity generation. The mass burning of MSW is primarily performed on a grate system that enables combustion air to be provided through the fuel bed with a variety of alternative methods of feeding fuel to the grate. The mass burn technologies that will be discussed here include: water wall incineration; rotary kiln furnaces; and multiple hearth incinerators (Williams, 2005).

Water wall incineration

This is the most popular mass burn furnace. In the system an overhead crane is used to distribute waste evenly into a hopper and pistons are used to ram the waste from the hopper onto a grate. The grate then moves across the combustion chamber where it is exposed to high temperatures. Air is also fed in from above and below the grate. The air from below the grate initiates the combustion reaction and is called “under fire air,’ while the air from above, the “over fire air,” is introduced through nozzles and creates a more uniform distribution of combustion gases in the chamber. This thereby ensures a more complete combustion of volatile substances. The ash from this process is moved in a water quench pit and is later taken through other processes for further treatment. The flue gas produced in a water wall furnace can then be used to generate electricity. The gas goes into a waste heat boiler where the gas converts water into high pressure steam. This steam is used to drive a turbine. At the end of this turbine is an alternator which converts the energy into electricity (Knox, 2005).

Rotary Kilns

In a rotary kiln waste is burnt in a rotating cylinder. The rotary kiln is a cylindrical refractory lined shell that is rotated to provide a tumbling and lifting action to the solid waste materials. The solid waste is fed into the rotary kiln whete the bulk of the combustion takes place and then moves along the chamber in a countercurrent configuration with respect to the gas flow. This exposes the waste surface to the flames from fuel burning as well as liquid waste burning in the rotating kiln. Rotary kilns involve a large variety of combinations of processes that include particulate mixing, gas-solid or solid-phase reactions with intensive heat and mass transfer. The kiln is operated with a semicontinuous feed and continuous discharge. It has a secondary chamber to ensure complete combustion of the waste. In practise, the kiln acts as the primary chamber to volatilize and partially or totally oxidise the combustible materials in the waste. Inert as is then removed from the lower end of the kiln. The volatilized combustibles exit the kiln and enter the secondary chamber where additional oxygen is introduced along with ignitable liquid wastes to achieve the desired operating temperature (Rovaglio et al, 1998).

Multiple Hearth Incinerators

This type of incineration is used for both medical and MSW incineration. The key feature of this technology is that several grates are used. Waste descends sequentially through the grates into hotter and hotter combustion zones. The result and benefit of this is that there is a high combustion zone residence time for most types of waste. Most forms of combustible industrial waste are suited for multiple hearth combustion and most of the moisture in the wastes is evaporated due to the high residence times (Mullen et al, 2000).

The multiple hearths are therefore divided into three zones (Mullen et al, 2000):

1. The upper hearths comprise the drying zone in which bio-solids, water and some organic compounds are volatised. The temperature in the drying zone is typically between 420 and 530°C.

2. The middle hearths comprise the combustion zone, in which temperature is typically 815 to 930°C. A series of burners are installed in the combustion zone to maintain the combustion temperature.

3. The lower hearths form the cooling zone. In this zone the ash is cooled as its heat is transferred to the incoming combustion air. The temperature in this zone is typically from 170 to 200 °C.

This system can use a variety of fuels and is therefore fuel efficient. However they are expensive to maintain and operate. Another point to note is that ash cannot be put into a multiple hearth system as it tends to fuse the ash into large rock like structures that may again trouble the system (Mullen et al, 2000).

Refuse Derived Fuel (RDF) Burning

RDF burning, as previously mentioned, is the process whereby waste is treated to improve its physical and chemical properties thereby making a more uniform fuel at a higher heat value. RDF systems do not mass burn MSW but rather separate it into combustible and non-combustible fractions. The combustible material that is sorted is called RDF and can be used in boilers. RDF feedstock is therefore easier to burn, needs lower excess air and hence works at an optimal efficiency. Handling of RDF is also easier as non-combustibles are removed. The main technology addressed here will be the fluidized bed unit (Kumar, 2000).

Fluidized Bed Incinerators

A bed of heated inert sand-like particles is used to transfer heat to the waste that is to be incinerated in a fluidized bed incinerator. The bed rests on a perforated metal plate called a distributor plate. Heated air is then pumped from the underside of the plate, through the perforations, into the bed. The air bubbles through the particles causing it to act as a fluid, thus the name “fluidized” bed incinerator. Both the waste and the bed are enclosed in the combustion chamber of the incinerator and emissions leave through the top of the enclosure. The fluidized Bed system is a closed system, resulting in many pollutants being trapped. However this can also pose difficulties as the residual waste that cannot be combusted is hard to remove (Kumar, 2005).

Benefits of Incineration

Incineration is responsible for a reduction in both volume and weight of MSW (approx. 90% volume and 75% weight reduction). This waste reduction is immediate and requires no long term residence in the incinerator. Incineration plants can generate electricity and heat that can substitute power plants powered by other fuels at the regional electric and district heating grid, and steam supply for industrial customers. Incinerators and other waste-to-energy plants generate at least partially biomass-based renewable energy that offsets greenhouse gas pollution from coal, oil and gas-fired power plants. In terms of climate change, the incineration of MSW avoids the release of methane if the waste is sent to landfill. Finally the bottom ash residue remaining after combustion has been shown to be a non-hazardous solid waste that can be safely put into landfills or recycled as construction aggregate. There is also scope to recover metals from the ash if this has not been done before (Michaels, 2009).

Problems

The main concern around waste incineration is the emissions that a plant can produce. Incinerators produce fine particles in the furnace and even with modern particle filtering of the flue gases, a small amount of these particles can be emitted to the atmosphere. The most publicized concerns from environmentalists about the incineration of MSW involve the fear that it produces significant amounts of dioxin and furan emissions. Dioxins and furans are considered by many to be serious health hazards. Other gaseous emissions in the flue gas from incinerator furnaces include sulphur dioxide, hydrochloric acid, heavy metals and particles (Bontoux, 1999).

Another negative factor to consider is that the building and operating of waste processing plants such as incinerators requires long contract periods to recover initial investment costs, causing a long term lock-in. Incinerator lifetimes normally range between 25 and 30 years. Over time if not managed properly, waste incinerator plants can fall into disrepair and subsequently become a health and safety hazard to communities and the environment in neighbouring areas (Bontoux, 1999).

4.2.2 Incineration Case Study: Brescia, Italy

Opened in 1998, the waste incinerator is situated in the south of the Commune of Brescia, approximately 300 meters from the city's residential area. Brescia's waste incinerator is designed to retrieve and treat non-recyclable refuse and use it within the power production process. The plant consists of three combustion units, one of which is connected to the steam turbine and burns biomass fuels. The plant has been designed with the latest technologies in mind and as a result of this there are lower emission levels than those required by current environmental regulations in the EU. The WtE plant recovers electrical and thermal energy from waste derived from differential collection (Carlesi, 2001).

The waste incinerator is an important source of power for Brescia. The town's remote heating network works in conjunction with the waste incinerator to not only produce electrical power, but also recycle a large amount of thermal energy generated by the cooling of the turbines. This thermal energy is then distributed into the remote heating network and used to heat individual's homes (Carlesi, 2001).

Any residual waste not incinerated during the combustion process (equivalent to about 10% of the entire volume of refuse treated by the plant) is transferred into landfills. Heavy combustion ashes can be further recovered while the ash collected from the filters is conveyed to suitable storage silos and inactivated by reducing the quantity or mobility of heavy metals present in the ash thereby ensuring that no harm can be caused (Carlesi, 2001). The main advantage of this process of vitrification is that it produces a vitreous material, which is of "satisfactory chemical stability, while it can also homogeneously incorporate into its matrix numerous toxic elements" (Kavouras et al, 2002: 361)

The activities of the Brescia waste-to-energy plant consist of the following:

- waste input
- combustion process
- thermal recovery
- system of treatment of fumes and ashes

Waste input to the plant is "undifferentiated", that is, waste that cannot be usefully recycled, and arrives directly from the skips. Such undifferentiated waste is material that remains after the differentiated collection of the more essential parts that are recycled as materials. In Brescia 44% of waste is consigned to recycling, the objective is 50% (A2A, 2009).

After having been unloaded the waste is automatically batched on the moving grate where the temperature is constantly regulated at 1000°C to obtain complete combustion.
The gases derived from the combustion chamber then pass to a post combustion chamber where

the oxidation reactions are completed; in this phase a suitable mixture of water and ammonia is added to reduce nitric oxide. The fumes then enter the boiler where, in contact with water pipes, they emit heat and generate steam. The high-pressure steam is passed to a turbine for the production of electrical energy; the exhaust steam leaving the turbine heats the water that feeds the district heating system (A2A, 2009).

The waste incinerator plant at Brescia is able to burn 700,000 tons of refuse and biomass fuel each year. It produces up to 400 GWh of electrical power and 300 GWh of heat per year which in turn creates an annual savings roughly equal to one third of the power used in Brescia's heating network each year. In 2008 the waste to energy plant produced electricity equal to the needs of 190,000 families and heat equalling the requirements of 50,000 flats. At the same time it has prevented emissions of over 400 000 tons of carbon dioxide (A2A, 2009).

The emissions produced by the waste incinerator are lower than those emissions from plants which burn traditional fuels like coal or fuel oil. Furthermore, by using urban waste as an alternative to fossil fuels, the waste incinerator does not contribute any negative environmental impacts caused by the entire fossil fuel supply chain. Environmental awareness and responsibility is evident in Brescia: 50% of the cost of building the plant was devoted to the systems for scrubbing of combustion gases and to the protection of the environment (A2A, 2009). Exhaust fumes have also been an issue when looking at incineration. However the Brescia plant contains smells from exhaust and waste removal processes within hermetically sealed rooms ensuring that they do not leak into the surrounding areas (Carlesi, 2001).

The Brescia Waste to Energy plant was judged in 2009 as the best waste to energy plant in the world by WTERT (Waste to Energy Research and Technology Council), an arm of the Earth Centre of Columbia University in New York. The criteria that were adopted for evaluation are:

- efficiency in recouping electrical and thermal energy
- level of emissions obtained
- quality in the reuse and treatment of residues
- acceptance by the local community
- aesthetic and architectural quality

4.2.3 Gasification and Pyrolysis

Gasification and pyrolysis are similar thermal processes for treating MSW. They are however different from incineration as the process limits the conversion of MSW to form intermediates that are then used for energy recovery. In essence, the MSW is not combusted directly in either of these processes. These technologies, which operate in restricted oxygen environments, are sometimes known as Advanced Thermal Technologies and typically rely on carbon based waste such as paper, petroleum based waste like plastics and organic material including food scraps. The various wastes are broken down to create gas, solid and liquid residues.

What is Gasification?

Gasification is a process in which materials are exposed to a small amount of oxygen, but not enough to allow complete combustion to occur. MSW is physically and chemically changed through temperatures that are usually between 800° and 1100°C. The end products of gasification include solids, ash and slag, liquids and syngas. Gasification with pure oxygen (rather than air) results in a higher quality mixture of carbon monoxide and hydrogen and virtually no nitrogen. Gasification with steam is more commonly called "reforming" and results in a hydrogen and carbon dioxide rich "synthetic" gas (syngas). This syngas can be used in boilers to provide heat or can be cleaned up and used in combustion turbine generators. The gas has a calorific value equivalent to 25% of natural gas if ambient air is used or 40% if oxygen-enriched air is used, and is also dependent on the composition of the input waste into the gasifier (Klein, 2002).

What is Pyrolysis?

Pyrolysis is thermal degradation either in complete absence of an oxidising agent or with such a limited supply that gasification does not occur. Relatively low temperatures are employed of 500° to 800° compared to that of gasification. Three products are produced through the process: combustible gases (methane, hydrocarbons, hydrogen and carbon monoxide), liquid and solid residues (char). The relative proportions of these products depend on the pyrolysis method that is used and the reaction parameters that are in place. The type and quality of feedstock can also have some influence here (Beenackers, 1989).

The Process

It is common to find that most pyrolysis and gasification processes have four stages (FOE, 2009):

1. Preparation of waste feedstock: The feedstock used in the process may in the form of RDF produced by a Mechanical Biological Treatment plant. Alternatively the plant may take mixed waste and process it through a recycling facility in order to remove recyclable material and those materials present that have no calorific value (e.g. grit).
2. Heating the waste: This is done in a low-oxygen atmosphere (gasification) or no oxygen atmosphere (pyrolysis) to produce gases, liquids and solids.
3. Scrubbing: Scrubbing of the gas takes place to remove any particulated, hydrocarbons and soluble matter that would affect the purity of the gas.
4. Electricity Generation: The final stage is when the scrubbed gas is used to generate electricity or in other cases used to produce heat. There are different ways of generating the electricity from the scrubbed gas which include steam turbines, a gas engine and in its infancy hydrogen fuel cells.

Types of waste that can be processed

A wide variety of waste can be handled by both gasification and pyrolysis technologies. The main applications for the two technologies are to process agricultural and forestry residues and to recover energy from MSW and industrial waste (Faaij et al, 1997). Pyrolysis and gasification systems can handle unsorted MSW, although reliability is often bought into question. For this reason, the cost involved in segregating waste suddenly becomes very important when looking at either of these technologies. Gasification and pyrolysis technologies, when processing MSW, perform best when refuse derived fuel has been produced from MSW. A Rdf-fired system can be controlled more effectively than a mass fired system because of the homogenous nature of RDF. This type of material is well suited to the advanced technical nature of gasification and pyrolysis (Nemerow et al, 2009)

Benefits

Advanced thermal processes such as gasification and pyrolysis have certain benefits that are different to incineration. For starters, by using less oxygen, fewer air emissions may be produced. However, there are occasions when some of the oils and gases that are a result of the process end up being burnt and therefore can generate emissions. The processes claim to produce more useful products than incineration, including syngas and bio char, which can both be used for fuel as well as feedstock and a driver for electricity generation. Syngas can also be used to drive a gas engine, which in some cases is more efficient than a steam engine (FOE, 2009).

Problems

Pyrolysis and gasification can sometimes be seen to undermine recycling unless only residual waste is dealt with. However, most plants are unlikely to be able to deal with only residual waste as they need certain amounts of particular types of materials in order to work effectively and efficiently. These include paper, plastic and food waste. As a result both processes conflict with recycling and therefore the waste management hierarchy.

Like incineration, pyrolysis and gasification are also likely to produce emissions which can include acid gases, dioxins and furans, nitrogen oxides, sulphur dioxide, particulates, cadmium, mercury, lead and hydrogen sulphide. Solid residues that are a product of the process can include inert mineral ash, inorganic compounds, and any remaining unreformed carbon which can account for up to 15% of the original volume of waste (FOE, 2009).

The uncertainties around these technologies are also problematic. Much of the data on performance of the processes is given by private companies and can often be contradictory. Many incinerator companies claim superior efficiency to these alternative thermal processes, while the thermal companies claim the opposite. It is also not clear what kind of emissions will come out of the process, therefore the track record of gasification and pyrolysis in dealing with mixed municipal waste is debatable (Schilli, 2004). It is important to consider both pyrolysis and gasification as they are fast becoming attractive thermal technology options. What has also become apparent through this study is the lack of full scale implementation of both technologies. This is even more evident with pyrolysis, and as a result, this technology is not considered for analysis in the coming chapters. However, the information available for gasification was sufficient to use for further analysis.

4.2.4 Gasification Case Study: Akita City Gasification Facility

Japan's geographical location and size of population has meant that the country's solid waste management has become dominated by incineration. 67% of Japan's solid waste is processed in incineration facilities, one of the highest rates in the world. The reason for initial implementation was to address sanitation and landfill capacity concerns (Cohen, 2005).

In 1999, it was identified that incineration resulted in potentially carcinogenic emissions and this led to a policy shift. The Basic Guidelines for the Promoting of Measures against Dioxins were formulated in March 1999 to reduce emissions levels to approximately 10 percent of 1997 emissions levels. However the government was not willing to abandon incineration because Japan is small and the country is hot and humid, making it necessary to reduce and hygienically treat wastes (Cohen, 2005).

In 2000, Akita City secured subsidies from the Japanese government to construct two gasification chambers on an existing incineration site. This upgrade was met with very little public outcry and was a smooth transition. The City debated the type of gasification technology to be implemented and eventually decided on a Nippon steel-designed, shaft type gasification chamber because of its lower emissions and high reliability. The waste is passed through a shredder and then fed into a large vertical shaft furnace with a small amount of coke. A small amount of limestone is also added to the feedstock to reduce harmful emissions. The waste is dried and gasified at temperatures of around 2000 ^{o} Celsius. This temperature is achieved through the combustion of coke and a portion of the pyrolysis gas, which is a product of the process (Cohen, 2005).

This facility is capable of processing 440 tons of mixed waste per day. In 2003, the facility processed 125 000 tons of mixed waste. From this the facility generated 52.5 MWh of electricity through the combustion of pyrolysis gas producing an income of approximately $1.6 million. The 2003 average solid by-product of 100 tons of feedstock included 11.3 tons of slag and 2.1 tons of metal alloys which are reused, and 2.7 tons of ash which is landfilled. The remaining 85 tons go into the pyrolysis gas (Cohen, 2005).

Implementing a gasification facility would be a major financial undertaking for any city. Akita spent $174 million on a 125 000 tpa facility (in 2003 dollars). However, many manufacturers feel that construction costs continue to decrease and greater economies of scale can be achieved (Cohen, 2005).

4.3 Non-Thermal Technology – Anaerobic Digestion

Anaerobic Digestion (AD) occurs with the biodegradation of organic material in the absence of oxygen but with the aid of anaerobic micro-organisms. It is a process that is the consequence of a series of metabolic interactions amongst various groups of these micro-organisms. It is often used for industrial or domestic purposes to aid with the management of waste and to release energy. This energy is regarded as renewable because the process produces a methane and carbon dioxide rich biogas suitable for energy production helping replace fossil fuels. The digestate that is produced from the process is nutrient rich and can also be used as a fertiliser (Verma, 2002)

The Process

The process of AD can be divided into four stages: pre-treatment, waste digestion, gas recovery and residue treatment. A large number of digestion systems require pre-treatment of waste to obtain a homogenous feedstock. This pre-treatment involves separation of non-digestible materials and shredding. The waste received by AD's is more often than not source separated or put through mechanical handling systems. This ensures that there are no non-desirable materials in the feedstock such as glass, metals, stones etc. The waste can be shredded before it is fed into the digester. Once inside the digester, the feed is diluted to achieve desired solids content and remains in the digester for a pre-designated retention time. When dilution is required, a varying range of water sources can be used. These include clean water, sewage sludge or re-circulated liquid from the digester effluent. Once this occurs and the waste is digested biogas is formed and a digestate is left behind (Klass, 1998).

In the process of waste digestion there are three stages of metabolic interactions that take place:

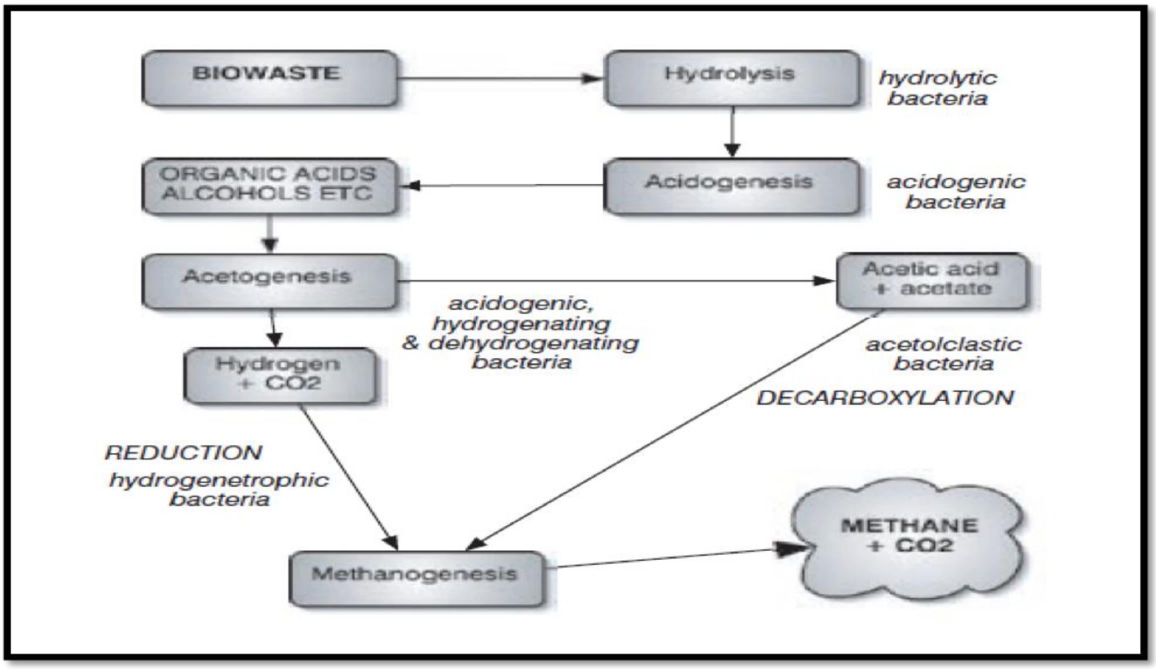
1. Hydrolysis: The initial stages of the decomposition invlve the hydrolysis and fermentation of the cellulosic, protein and lipd compounds in the waste by micro-organisms which can tolerate reduced oxygen conditions. Carbohydrates, proteins and lipids are hydrolysed to sugars which are then further decomposed to carbon dioxide, hydrogen, ammonia and organic acids. Gas concentrations may rise to levels of up to 80% carbon dioxide and 20% hydrogen (Williams, 2005)

2. Acidogenesis: The acid stage occurs when organic acids that are formed in the hydrolysis and fermentation stage are converted by acetogen micro-organisms to acetic acid, acetic acid

derivatives, carbon dioxide and hydrogen. Other organisms convert carbohydrates directly to acetic acid in the presence of carbon dioxide and hydrogen (Diaz et al, 1993)

3. Methanogenesis: The final stage of anaerobic digestion is the main methane gas forming stage. Low hydrogen levels promote the methane-generating micro-organisms, the methanogens, which generate methane and carbon dioxide from the organic acids and their derivatives generated in the earlier stages. (Williams, 2005)

Figure 6: Flowchart indicating the main stages in anaerobic digestion
Source: Evans, 2001



Operating Parameters

There are a number of important operating parameters that must be understood in order to ensure successful anaerobic digestion. These operating parameters must be controlled so that the microbial activity is improved and thereby the efficiency and gas recovery of the system is enhanced. These parameters include waste composition, pH level, temperature, carbon to nitrogen ratio, retention time and and mixing, as shown in Table 7.

Table 7: Operating Parameters of Anaerobic Digestion

Parameters	Description
Waste Composition	The municipal solid waste that is treated by AD will comprise of a biodegradable organic fraction. The biodegradable fraction includes food and yard waste. This municipal waste also includes a combustible fraction that can be made up of organic matter containing paper and cardboard and an inert fraction containing stones, glass, sand etc. It is necessary that the inert fraction be removed to landfill as it will create functional problems to the process and can damage equipment. The composition of waste can affect the yield quantities of biogas and the quality of biogas as well as the quality of the digestate left over (Verma, 2002).
pH level	Anaerobic bacterias growth can be stalled by high acidic conditions. It has been determined that the optimal pH value for AD lies somewhere between 5.5 and 8.5 so as not to stray to levels of high acidity or alkali. The amount of time that the digestate is present in the system also affects the pH value (Verma, 2002).
Temperature	The mesophilic and thermophilic are the two temperature ranges that provide optimum digestion conditions for the production of methane. The mesopilic range is between 20° and 40°C while the optimum temperature is considered to be 35°. The thermophilic temperature range is between 50° and 65°C with the optimum temperature being 55°C (Mata-Alvarez et al, 2000).
Carbon to Nitrogen Ratio (C/N)	Optimum C/N ratios in anaerobic digesters are between 20 and 30. If the C/N ratio is high then there will be a lower gas production. Conversely, a lower C/N ration causes ammonia accumulation and an increased pH value above 8.5. To achieve optimum C/N ratios materials of high and low C/N ratios can mixed, such as solid waste mixed with sewage or animal manure (Verma, 2002).
Retention Time	The necessary retention time for completion of the AD reactions vary with differing technologies, process temperatures and the composition of the waste. The retention times for wastes treated in a mesophilic digester range from 10 to 40 days with lower retention times required for digesters in the thermophilic range (Verma, 2002).
Mixing	Mixing is an important process in a digester as it blends fresh material with digestate that contains the necessary microbes. Mixing also goes some way to preventing scum formation and temperature gradients (Klass, 1998).

Digesters

There are two types of digester systems, namely wet and dry, where any system with solid content below 15% is termed wet. Digesters can also operate within two temperature ranges. The first is at 35°C called mesophilic and the second is at 55°C called thermophilic. Other differences are that some digesters are loaded in batches while some require continuous feeds. When a process is completed and the digesters are emptied it is necessary to leave approximately 10 – 15% behind as it will act as a seed for the next batch (Mata-Alvarez et al, 2000).

These various conditions have led to different digesters being developed. Some plants are designed to optimise gas collection for energy production while others might look to optimise the horticultural product thereby making energy a secondary goal. However regardless of the aims of each plant each process shares a common approach: shredded materials and water are held in a reactor for 6 – 25 days at a constant temperature between 33°C and 55°C. The process of AD in a digester takes approximately 35 days. Also it must be noted that purity of the material that is fed into the AD process determines the quality of the end product (Mata-Alvarez et al, 2000). The five main types of anaerobic digestion processes are covered in more detail in Appendix F.

Digestate use

There is a residual fibrous material left at the end of the AD process and this is called the digestate. This digestate has a number of uses including landfill cover, compost for agriculture or the production of high quality soil conditioner. The quality of the digestate is determined by the quality of the waste composition. Source separation is also important to the quality of the digestate as contamination with toxic chemicals and non-biodegradables' affects the final product (AGAMA, 2009). The digestate is generally not suitable for putting directly onto the land. The digestate is often too wet, can contain a significant amount volatile fatty acids which can by phyto toxic and, if digestion has not occurred within the thermophilic range of temperatures, are not hygienised. Therefore if one is to use a digestate as compost it is generally accepted that post-treatment needs to take place in order to obtain a high-quality, finished product (Mata-Alvarez et al, 2000).

Biogas

Biogas is one of the products produced during anaerobic digestion. The components of this biogas are between 55 – 70% methane by volume and 30 – 45% carbon dioxide by volume. Hydrogen

Sulphide is also found in the biogas with anywhere between 200 – 4000 parts per million. The quality of the biogas produced from AD significantly affects how it is used. The main issue when looking at biogas is how much hydrogen sulphide is present. If there is too much found it can rapidly corrode the gas-handling and electricity generating equipment in the AD plant (Verma, 2002).

Energy use

Energy recovery from the biogas that is produced in the AD can be in the form of heat and/or electricity generation. AD is a net-energy producing process, producing between 75 and 150 kWh/t of municipal solid waste if the biogas is burned for electricity (Vik, 2003). A biomass power plant consists of the following components (AGAMA, 2009):

- raw material biomass storage
- fermentation chambers
- biogas tank (low pressure)
- electricity generator
- controls and automation system

The power output capacity of such plants can range from 0.3 to 5.5MW per annum depending on the size of the plant. Most large plants that are designed to use MSW use combined heat and power plants (CHP) to produce electricity and heat water (AGAMA, 2009).

Benefits

The benefits of AD are numerous. Firstly the process helps to reduce greenhouse gas emissions compared to other waste management options. A well managed AD system will look to maximise methane production but not release any gases into the atmosphere. The feedstock for AD is a renewable source and therefore does not deplete fossil fuels. Energy produced through this process can reduce dependency on fossil fuels. It also produces a sanitised product that is suitable for composting and the nutrients in the digestate are more available to plants. The wastes that are digested during the process do not emit as much odour as those that are not digested. Finally the energy that is generated reduces treatment costs and produces energy that is renewable (Monnet, 2003)

Problems

AD technologies yield a reduced volume of sludge which yields odour problems. Biogas produced through non thermal processes usually consists of CO_2, CH_4, N_2 and H_2S. The important thing is to minimise these issues wherever possible. AD has significant capital and operational costs and will therefore not be effective as a standalone energy source. Rather it should form part of an integrated system. There may be some health and safety risks with the pathogenic content of the feedstock. This can however be avoided through appropriate plant design and proper handling procedures (Monnet, 2003).

4.3.1 Anaerobic Digestion Case Study: Tilburg, the Netherlands

Since 1994, Dutch municipalities have had a mandate to collect organic waste separately from other forms of solid municipal waste. An association, called SMB, was created that included 9 municipalities with 500 000 residents who produce 40 000 tons of organic waste per annum. This association was responsible for the implementation and running of technologies that would process the organic waste from the region. The technologies that are used commonly to treat this waste are aerobic digestion for compost production and anaerobic digestion to produce biogas. There has however been little experience with large scale waste treatment in the Netherlands and therefore the main objective of the project was to evaluate the technical, economic and energy performance of the biogas technology and to also assess the environmental impacts (EUKN, 2000).

The site built in Tilburg consists of a landfill site, a new biogas plant and an upgrading plant where the biogas is upgraded and cleaned to natural gas quality and fitted into the extensive gas network of the region. The degradation of the waste is done in several stages using specific bacteria and condition and allows for the production of a biogas with a high content of methane (EUKN, 2000).

After arrival, the waste is pre-treated by means of shredding, screening and iron separation. The waste water is partly re-used processing water and the remaining waste water is drained to a nearby waste water treatment plant.

Table 8: Technical parameters for biogas plant in Tilburg (EUKN, 2000)

Digestion temperature	37-40 °C
pH	7.1
Retention time	24 days
Organic volume load	7.0-8.6 kg VDM1/m^3/day
Methane content	55%
Methane production	200-250 Nm^3/tons VDM
Annual capacity	52,000 tons of organic waste
Annual load	40,000 tons of organic waste
Net biogas production	1.6 million Nm^3/year
Energy	14.7 GWh
Saved CO_2-emmision	3000 Tons/year
Saved NOx-emission	5.3 Tons/year

The biogas productivity is roughly 75 Nm^3 biogas/ton received waste. This productivity varies during the year; it increases during the winter and decreases during summer. The investment to the biogas plant was approximately €16 million.

So far, the waste digestion plant has produced three million Nm^3 of biogas per year, with a methane content of approximately 55%. This is converted in the upgrading plant to 1.6 million Nm^3 of gas with natural gas quality. Afterwards it is transferred into the gas distribution network (EUKN, 2000).

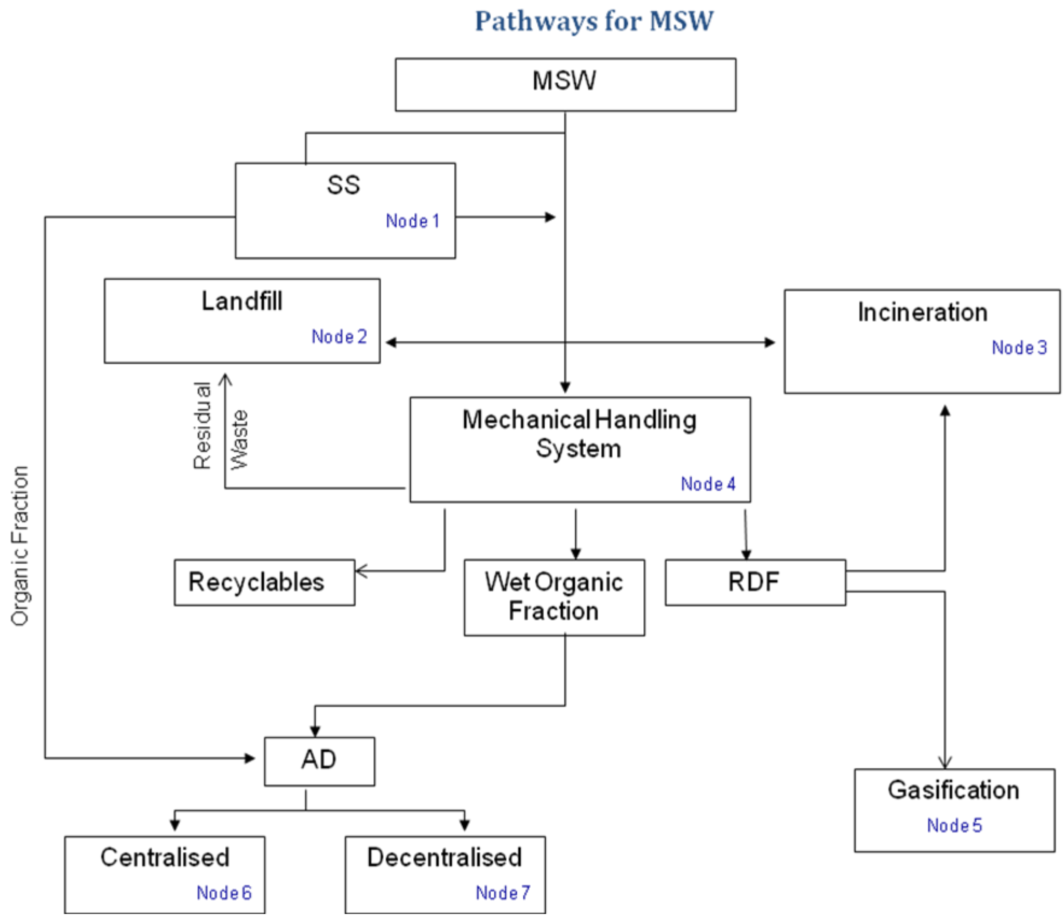
The yearly energy production is 18 GWh, of which 3.3 GWh (300,000 Nm^3 of natural gas) is used for process heat at the plant itself which means that 14.7 GWh is sold to the gas distributor (EUKN, 2000). The plant produces 18,000 tons of digestate annually. It is possible to produce high quality compost from this digestate, but due to lack of finances, this has not been done to date (EUKN, 2000).

4.4 Pathways for Municipal Solid Waste

When considering WtE as part of an integrated waste management plan for any city, decision makers are required to look at the steps that need to take place to prepare the waste for optimal processing, not just the WtE technology itself. People often consider WtE technologies in isolation and this can result in a lack of information and therefore uninformed decisions. This thesis looks to contribute by moving away from this isolated analysis and rather look at the infrastructure needed to support WtE technologies. By looking at the pathways that MSW can take to get to a WtE technology, one gains a greater insight into the considerable measures that would need to be implemented to carry out a successful operation. It is not just a case of collection of waste and putting it into a technology. As an example, anaerobic digestion and gasification require that the waste is sorted and treated so that it is in a suitable state to be processed. The remainder needs to be recycled or landfilled.

Figure 7: Pathways for municipal solid waste

Adapted from Kiser and Burton, 1992



In figure 7, adapted from Kiser and Burton (1992), MSW has a number of pathways that it can travel on to arrive at a particular end destination. Nodes 1 through 7 each represent a stage in a potential pathway for MSW. For instance if one were to look at organic waste, it can either go straight to landfill, can be source separated and then sent to an AD facility or alternatively organic waste can be processed though a mechanical handling system and then sent to an AD facility. By carrying out an analysis in this form, a decision-support tool is created allowing decision makers to make a more informed, holistic decision by evaluating, rating, and comparing different alternatives.

4.5 Non-WtE node descriptions

Figure 7 represents the pathways for municipal solid waste when integrating WtE technologies. There is infrastructure that is required for successful implementation and also so that the hierarchy of waste management is not disregarded. Source separation, landfill sites and mechanical handling systems form the non-WtE components of the pathways and short descriptions are provided below. The WtE technologies themselves have been discussed previously in sections 4.2 and 4.3.

4.5.1 Source Separation (Node 1)

Source separation is seen as a critical element when constructing an integrated waste management programme and forms part of the re-use, recovery and recycles activities of the programme. By separating waste at source for recycling, it minimises the need for waste to go to landfill.

The City of Cape Town's "Think Twice" campaign was launched to encourage pilot source separation in five metros in the City. What has become abundantly clear is that for the City to run this service is financially prohibitive. It is therefore now seen as a service that should be offered by the private sector, providing there is a sustainable business platform (CoCT, 2010).

4.5.2 Landfill (Node 2)

Currently, the City of Cape Town has six landfill sites. Only three of these are in operation and will reach their capacity within the next five to 13 years. Currently new locations are being assessed for a new site to cope with the city's growth. Swartklip, Brackenfell and Faure no longer accept waste as they are all full. Consequently two new sites are being considered for a new landfill. The first is south of Atlantis within the Koeberg exclusion zone, the second is at KalbasKraal near Philidelphia, also up the West Coast. The City estimates that the final expenditure will be between R1.2 and R2 billion. One must bear in mind that these sites are not within close proximity to Cape Town and therefore additional costs of transport will make these sites more cost prohibitive than their predecessors (CoCT, 2010).

4.5.3 Mechanical Handling System (Node 4)

Complex processes like gasification and pyrolysis require a feedstock that is high quality and has a high calorific content. This enables these systems to operate at an optimal level. Conversely, anaerobic digestion does not operate with a stream that contains anything but organic waste. Any foreign objects will result in system breakages and failures. General municipal waste is therefore not suited to either of these processes. Rather the waste needs to be separated into its two fundamental fractions, wet organic fraction and dry solid fraction.

RDF is the product of treating a waste to improve its physical and chemical properties thereby making a more uniform fuel with a higher heat value. A mechanical handling system is used for the manufacture of refuse derived fuel. RDF is produced by shredding MSW, once non-combustible materials such as glass and metals are removed. The residual material of the process is sold as-is or compressed into pellets, bricks, or logs. RDF feedstock is therefore easier to burn, needs lower excess air and hence works at an optimal efficiency. Handling of RDF is also easier as non-combustibles are removed. (Kumar, 2000)

The process that will be considered here is one which produces a high calorific fraction from MSW which can be used as RDF in a mechanical biological treatment plant. In a mechanical biological pre-treatment plant metals and inerts are separated out and organic fractions are screened out for further stabilisation using composting processes, either with or without a digestion phase. It also produces a residual fraction called RDF which has a high-calorific value as it is composed mainly of dry residues of paper, plastics and textiles. It is important to note that there are simpler systems available. These are driven by manual labour and may be better for South Africa as it will result in a large amount of job creation.

4.6 Conclusion

The chapter has provided an insight into the technical and intricate nature of non-thermal and thermal waste-to-energy technologies. Each of the technologies mentioned has its own merits and weaknesses but continue to develop to an optimal and efficient operational status. Changes in domestic and regional policy and environmental requirements means that waste-to-energy technologies continue to evolve and therefore what may not be suitable, cost prohibitive or comparatively inefficient now may advance in the near future to a status that allows them to be considered as a serious option.

The final section of the chapter looked at the pathways for municipal solid waste and how WtE can form part of an integrated waste management system. This was followed by a description of the non-WtE elements of the pathways. A study of this kind will provide insight for a number of reasons.

Many decision makers often look at WtE in isolation. However, the merit of this study is that it looks at WtE from a more holistic approach and how these technologies will form part of an integrated system. Once this is established it is important to analyse different pathways by looking at a set of assessment criteria. The technologies and pathways for this study are assessed by looking at specific financial indicators. These indicators will provide information on the merit of the technologies and pathways that will be assessed. The following chapter will look at the assumptions of the financial models that were created to carry out the financial analysis of each WtE and MSW pathway.

Chapter 5: Financial Model Descriptions and Assumptions

5.1 Background

The purpose of this study is to move away from isolated WtE analysis and rather look at the integrated system that would need to be put in place for successful implementation of a specific WtE technology. However what must first take place is a study of the financial performance of the individual WtE technologies that were discussed in the previous chapter: incineration, gasification and anaerobic digestion. This financial performance will be assessed by looking at a set of financial indicators. These indicators are net present value, return on investment, the levelised cost of electricity and the levelised cost of waste, and will be described in more detail at the start of this chapter.

The chapter will then look at the assumptions used in the financial models created for: incineration (node 3); gasification (node 5); centralised anaerobic digestion (node 6); and decentralised anaerobic digestion (node 7). Each model's assumptions have led to a set of results that will be interpreted to analyse the financial performance of each technology.

Summaries of the spreadsheet-based models and evaluations for each of the four scenarios have been included in the appendices. The incineration scenario is covered in Appendix G, the gasification scenario covered in Appendix H, the centralised anaerobic digestion scenario covered in appendix I and the decentralised anaerobic digestion scenario is covered in appendix J.

5.2 Financial indicators

Financial models have been created for each of the WtE technologies (nodes 3, 5, 6 and 7) that analyse the performance of these technologies towards identifying a preferred technology. These financial models each use as inputs the capital cost of the technologies, operating costs of the plant once construction is complete and potential income from selling various outputs including electricity generated, carbon credit sales and the benefits from landfill airspace savings. These inputs are then used to calculate net present value, return on investment, the levelised cost of energy and the levelised cost of waste of each technology.

5.2.1 Net Present Worth (NPW)

Net Present Worth is the present value of an investment's future net cash flows minus the present value of the capital investment (Turton et al, 2003: 268). If the NPW is positive, then the project provides a return at a rate greater than the discount rate used in the calculations and therefore the investment should be made (unless an even better investment exists). If the NPW is less than zero then the investment should not be made. When making comparisons of investments, the larger the net present worth, the more favourable is the investment (Turton et al, 2003: 268).

Equation 1: Net Present Worth

$$\sum_{t=1}^{T} \frac{C_t}{(1+r)^t}$$

Where:

t - The time of the cash flow

r - The discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.)

C_t - the net cash flow (the amount of cash, inflow minus outflow) at time *t*.

5.2.2 Return on Investment (ROI)

A performance measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments. To calculate ROI, the financial gains of an investment are divided by the cost of the investment. The subsequent result is expressed as a percentage or a ratio. ROI does have a shortfall as an indicator as it does not use the time value of money at any stage and therefore could be seen as being less representative of the financial performance of a long term project (Turton et al, 2003: 265).

Equation 2: Return on Investment

$$\text{ROI} = \frac{(\text{Gain from Investment} - \text{Cost of Investment})}{\text{Cost of Investment}}$$

5.2.3 The Levelized Cost of Electricity

The levelized cost of the production unit quantifies the unit cost of electricity (in kWh) generated during the facility lifetime; and allows the immediate comparison with the cost of other alternative technologies (Palacios et al, 2010). If one looks at the equation below it can be broken down as follows:

Equation 3: Levelised cost of electricity

$$\underset{(R/kWh)}{\text{Total costs}} = \underset{(R/kW\text{-}yr)}{\text{Annualised Fixed costs}} \;/\; \underset{(fraction)}{\text{Capacity factor}} \;/\; h/yr + \underset{(R/kWh)}{\text{Variable costs}}$$

- The annualised fixed costs (R/kw-yr) are equal to the investment cost, multiplied by the capital recovery factor added to Fixed O&M costs. The capital recovery factor is represented by the following equation:

$$= \frac{r \cdot (1+r)^T}{(1+r)^T - 1} = \quad -PMT(r,T,1)$$

  Where r = discount rate and T = project life

- The capacity factor of a technology/production facility for a given year/period is the ratio between the energy produced during the year and the energy that would have been produced had the technology been producing at its maximum capacity throughout the year/period.
- h/yr is the amount of hours that a facility is in operation during a calendar year.
- Variable costs are calculated by dividing efficiency by the fuel costs and adding variable O&M costs. For the purposes of this study, the fuel i.e. the waste is not a cost to the facility and therefore this amount is zero.

5.2.4 The Levelized Cost of Waste

The levelised cost of waste indicator has been developed by adapting the levelised cost of energy to be analogous to that measure and therefore allow an easier comparison to other waste management options. The levelized cost of the production unit quantifies the unit cost of waste (in tons) processed during the facility lifetime; and allows the immediate comparison with the cost of other alternative technologies. If one looks at the equation below it can be broken down as follows:

Equation 4: Levelised cost of waste

$$\underset{(R/ton)}{\text{Total costs}} = \underset{(R/ton\text{-}yr)}{\text{Annualised Fixed costs}} \;/\; \underset{(fraction)}{\text{Capacity factor}} + \underset{(R/ton)}{\text{Variable costs}}$$

- The annualised fixed costs (R/ton-yr) are equal to the investment cost, multiplied by the capital recovery factor added to Fixed O&M costs.
- The capacity factor of a technology/production facility for a given year/period is the ratio between the tons of waste processed during the year and the tons of waste that would have been processed had the technology been producing at its maximum capacity throughout the year/period.
- Variable costs are calculated by dividing efficiency by fuel costs and adding variable O&M costs. For the purposes of this study, the fuel i.e. the waste is not a cost to the facility and therefore this amount is zero.

5.3 Assumptions of Financial Models

5.3.1 General Assumptions

Most of the general assumptions of the incineration and gasification financial models have been taken from the study carried out by AGAMA Energy in 2006 and are shown in Appendix G. These general assumptions are also applied to the centralised and decentralised AD models, although specific CAPEX and OPEX values have been gathered from other sources for centralised AD. The general assumptions include income streams, cost of EIA's, land purchase, project design, commission and construction, depreciation, working capital, the discount rate and the tax rate. In addition, the composition, gross calorific value, hydrogen content, energy content and moisture content of Cape Town's MSW can all be found in Appendix C. These are used to calculate the actual amount of energy generated by a technology.

Generated incomes from steam and electricity sales, landfill airspace savings and avoided emissions were used to carry out the financial analyses. The lifespan of the incineration, gasification and centralised AD facilities have been estimated at 20 years (AGAMA, 2006). Given that the Agama study was conducted in 2006, all figures have been inflated to present day values using an inflation rate of 5%,a conservative rate of inflation. Year 0 in each model represents 2010. The figures for the centralised AD model have been acquired from European case studies, specifically AD plants found in the Netherlands and Barcelona, while the figures for the decentralised AD model were acquired from AGAMA (2010). Transport costs have not been considered so that the technologies can be compared from the point where waste is received by the processing facility.

5.3.2 Specific Assumptions for the Incineration Financial Model

Much of the financial data that was used in the financial model for incineration is based upon figures from Europe. This data was provided by incineration manufacturers contacted through the course of the research carried out. There are no large scale municipal solid waste incineration plants in Africa.

i.) CAPEX Assumptions for Incineration: The CAPEX assumptions for incineration include the capital cost of the technology, a gas holder and the area of the land required for the facility.

Table 9: CAPEX assumptions for incineration financial model

Parameter	Amount	Reason for Choice
Capital Cost of Technology including gas holder	Estimated at R819 million for a facility of between 30 – 40 MW of electricity output per annum. R750 000 is set aside for the gas holder	This estimate is based on European prices and includes gas analysers that are required under the Clean Air Act of the United States (EPA, 2008). One thing to note when looking at incineration is that the cost of a similar unit with X times the capacity of the first is $X^{0.9}$ times the cost of the initial unit. This is because there are limited economies of scale due to the emissions treatment requirements needed at an incineration facility. The price of the gas holder is based on European prices (AGAMA, 2006).
Land Requirement for site	10 hectares	There is a large amount of infrastructure that must be built around the incineration facility. This will include administration offices, roads and the necessary space for the stockpiling of a sufficient amount of waste. 10 hectares will be sufficient for this and also takes into consideration the possibility of site expansion in the future (IPPTS, 2010).

ii.) OPEX Assumption for Incineration: The operating costs for the incineration facility consist of labour, monitoring, maintenance, waste management, provision for contingencies and others. Each of these, barring provision for contingencies, will only begin to be accounted for in the first year of operations, year 5, and have been adjusted at the annual inflation rate of 5% from year 0. Many of these estimates have been adapted from the AGAMA study (2006) and changed where necessary on the advice of industry experts (Purser, personal interview, 2010).

Table 10: Operating costs assumptions for incineration financial model (in 2010 Rands)

Parameter	Level	Reason for choice
Labour	R9.72 million	Operating costs only begin once operations have begun in year 5 and are inflated from year 0. Thereafter labour is inflated by 5% per annum for the 20 years of operation. Much of the literature on labour needs of thermal plants looks at 24 staff required for system ranging from 100 000 tpa's to 500 000 tpa's at €45 000 per operative working in two daily shifts. This salary will not be as high for South Africans. The estimate given is in line with the literature available and has been adjusted for South African labour (Yassin et al, 2009: 319)
Monitoring	R 720 000	Incineration requires that emissions are monitored at all times. Gas analysers that are in place will carry out this function and are fully automated. The only cost will be the monthly calibration that is required for each analyser, at R10 000 per analyser per month (Endress&Hauser, personal interview, 2010). For incineration there are 6 analysers required to monitor carbon monoxide, sulphur dioxide, hydrogen chloride, hydrogen, oxides of nitrogen and particulates. All of these need to be monitored under the emission standards set by the European Union. It is these standards that have been used in the development of South Africa's own Clean Air Act, which will be promulgated in the coming months (TodaySure, personal interview, 2010)
Maintenance	R24.50 million	Maintenance is estimated at 3% of capital cost of the technology (Purser, personal interview, 2010). This is in line with estimates put forward by incineration companies in Europe (TodaySure, personal interview, 2010) and also

		available academic literature (Yassin et al, 2009)
Waste Management	R300 000	This provision is given for the waste that will be present in the facilities stockpiles and also the residual waste and ash that will be present at the end of the process and will therefore require removal off-site (Cohen, 2005). The estimate provided here is taken from the AGAMA study of 2006.
Other	R3.65 million	Other costs cover both operating and organization costs that may not have been realised here. These include power, heat, supplies and other services which must be maintained irrespective of the amount of waste processed (Peters et al, 2003: 391). This estimate is based on the study carried out by AGAMA in 2006.
Provision for Contingencies	R10 million	Contingencies act as a buffer in plans to enable response to any change and risk that occurs. Contingencies are essential and are not a sign of poor planning. Most important is the degree of contingency that is built in and how it is allocated (Netwon, 2005: 115). This number is not accounted for during year 0 and year 1. In years 2 and 3 contingencies are estimated at 5% of CAPEX of those years respectively as additional contingencies may be required during the building of the facility. In the first year of operations, contingencies reverts back to R10 million per annum (Purser, personal interview, 2010).

iii.) Size of facility: The size of the incinerator is assumed to have a treatment capacity of 500 000 tons per annum (tpa), which at current City estimates is roughly 25% of the total MSW generated. The 500 000 tpa estimated for the City of Cape Town plant is arrived at by excluding any recyclable materials that are found in the MSW as this is preferred in terms of the waste hierarchy. If waste streams including metal, glass and paper are source separated, there is only 68% of the total waste stream left for incineration. However, recycling initiatives are not 100% efficient and therefore some residual recyclable waste will end up being thermally treated. Similarly, provisions have been made for potential growth of the amount of waste that could be treated in the future, as current growth trends are 7% per annum with 2009 generation at over 2 million tonnes of MSW (AGAMA, 2006).

Waste incineration facilities can handle totally unprocessed MSW streams. Based on an analysis made by AGAMA Energy (2006), and the author's own literature review, 500 000 tpa falls within the range of capacities seen at international incineration facilities.

The energy recovery efficiency from incineration plants will vary in terms of plant design and also the type of energy cycle used. However power generating efficiencies are lower in an incineration plant than for large utility power stations. Literature shows that 1 kg of MSW has an energy content of 6MJ. One MJ has an equivalent MWh value of 0.0003 therefore 6MJ/kg is equal to 0.0018MWh/kg. If 500 000 tonnes of MSW are processed annually then this feedstock has an energy potential of 900 000 MWh. With an electrical efficiency of 30%, a total amount of 270 000 MWh per annum of energy can be yielded (Murphy&McKeogh, 2004).

This is once again in line with European estimates, although is lower than Brescia facility's output at around 450 000MWh per annum. Cape Town's estimate may be high or lower depending on the waste streams that are included in the feedstock. In house electricity consumption is estimated at between 10 and 15% of the electricity production, meaning that roughly 90% of electricity generated is delivered to the grid (AGAMA, 2006).

5.3.3 Specific Assumptions of Gasification Financial Model

Much of the financial data that was used in the financial model for gasification is based upon figures and estimates from Europe and the study carried out by AGAMA in 2006.

i.) CAPEX Assumptions for Gasification: The CAPEX assumptions in this instance include the capital cost of the technology, a gas holder and the cost of the land required for the facility.

Table 11: CAPEX assumptions for gasification financial model

Parameter	Level	Reason for Choice
Capital Cost of Technology including gas holder	Estimated at R954 million for a facility that has a capacity of 55 – 70 MW of electricity produced per annum. R750 000 is set aside for the gas holder	This estimate is based on European prices. The capital cost is related to the amount of waste processed by the facility. This is assumed to follow the six-tenths factor rule. According to this rule, if the cost of a given unit at one capacity is known, the cost of similar unit with X times the capacity of the first if $X^{0.6}$ times the cost of the initial unit (Peters et al, 2003: 242). The price of the gas holder is based on European prices (AGAMA, 2006).
Land Requirement for site	10 hectares	The plant will only take up 50% of the site. The rest of the site will be used for roads, administrative areas, incoming waste product storage and sorting. 10 hectares will be sufficient for this and also takes into consideration the possibility of site expansion in the future (Bellwether, personal interview, 2010).

ii.) OPEX Assumption for Gasification (AGAMA, 2006): The operating costs for the gasification facility have been divided up into labour, monitoring, maintenance, waste management, provision for contingencies and others. Each of these, barring provision for contingencies, will only begin to be accounted for in the first year of operations, year 5 and have been adjusted at the annual inflation rate of 5% from year 0. Many of these estimates have been adapted from the AGAMA study (2006) and changed where necessary on the advice of industry experts.

Table 12: Operating cost assumptions for gasification financial model (in 2010 Rands)

Parameter	Level	Reason for choice
Labour	R9.72 million	Operating costs only begin once operations have begun in year 5 and therefore labour is inflated by 5% per annum for the 20 years of operation. Much of the literature on labour needs of thermal plants looks at 24 staff required for system ranging from 100 000 tpa's to 500 000 tpa's at €45 000 per operative working in two daily shifts. This salary will not be as high for South Africans. The estimate given is in line with the literature available and has been adjusted for South African labour (Yassin et al, 2009: 319)
Monitoring	R 840 000	Gasification requires that emissions are monitored at all times. Gas analysers that are in place will carry out this function and are fully automated. The only cost will be the monthly calibration that is required for each analyser, at R10 000 per analyser per month (Endress & Hauser, personal interview, 2010). For gasification there are 7 analysers required to monitor carbon monoxide, sulphur dioxide, hydrogen chloride, hydrogen, oxides of nitrogen, oxygen and particulates. All of these need to be monitored under the emission standards set by the European Union. It is these standards that have been used in the development of South Africa's own Clean Air Act, which will be promulgated in the coming months (TodaySure, personal interview, 2010)
Maintenance	R76.32 million	Maintenance is estimated at 8% of capital cost of the technology. This could be as high as 10% because of the need for controls, safety devices, intrinsically safe equipment (instrumentation needs to be explosion proof) at a gasification facility (Purser, personal interview, 2010). Gasification technology providers in the US and Germany estimate that maintenance costs will be between 5% and 10% of capital costs (Bellwether, personal interview, 2010). This is also in line with estimates in academic literature of 5% for

		gasification technologies (Yassin et al, 2009)
Waste Management	R300 000	This provision is given for the waste that will be present in the facilities stockpiles and also the residual waste and ash that will be present at the end of the process and will therefore require removal off-site (AGAMA, 2006).
Other	R3.65 million	Other costs cover both operating and organization costs that may not have been realised here. These include power, heat, supplies and other services which must be maintained irrespective of the amount of waste processed (Peters et al, 2003: 391). This estimate is based on the study carried out by AGAMA in 2006.
Provision for Contingencies	R10 million	Contingencies act as a buffer in plans to enable response to any change and risk that occurs. Contingencies are essential and are not a sign of poor planning. Most important is the degree of contingency that is built in and how it is allocated (Netwon, 2005: 115). This number is not accounted for during year 0 and year 1. In years 3 and 4 contingencies are estimated at 5% of CAPEX of those years respectively as additional contingencies may be required during the building of the facility. In the first year of operations, contingencies reverts back to R10 million per annum (Purser, personal interview, 2010).

iii.) Size of facility: Akita City's gasification facility in Japan processes 125 000 tpas (Cohen, 2005: 37). Changchun's gasification facility in China processes 140 000 tpas while Karlsruhe in Germany processes upwards of 225 000 tpas (GAIA, 2006). Each of these facilities deals with unsorted MSW. However greater efficiencies can be achieved by using RDF for gasification. This has been shown in Chianti in Italy and Zeeland in the Netherlands, both of which have implemented successful gasification plants using RDF. The capacity of these plants was between 50 000 and 100 000 tpas, although this data was collected in 2000 (Morris & Waldheim, 2000). For the gasification plant it has been assumed that an amount of 225 000 tpa of RDF feedstock will be treated. One ton of MSW results in 0.3 tonnes of RDF being produced. If one were to estimate that 750 000 tons of MSW were processed by a mechanical handling system in one year, then 225 000 tonnes of RDF would be produced.

There would be residual waste that would end up at landfill and recyclables would also be separated by the process (Leavens, 2003).

The products of gasification can be used for varying types of energy conversion processes. These include burning in a combustion chamber, running a condensing turbine cycle or a combined heat and power cycle, a gas turbine to provide for example peak load power, or a gas and steam cogeneration plant. The application determines the efficiency of an energy recovery. One factor that does need to be considered is that often the produced fuels need post product treatment to remove components (such as sulphur) that may damage the engines, and this may therefore require further energy investment.

Literature shows that 1 kg of RDF has an energy content of 23MJ. One MJ has an equivalent MWh value of 0.0003 therefore 23MJ/kg is equal to 0.0069MWh/kg. If 225 000 tonns of RDF are processed annually then this feedstock has an energy potential of 1 552 500MWh. With an electrical efficieny of 35%, a total amount of 543 375 MWh per annum of energy can be yielded (Murphy&McKeogh, 2004).

5.3.4 Specific Assumptions of Centralised Anaerobic Digestion Financial Model

The capital investment required for a modern centralised AD plant is less than those of energy from waste thermal plants. Experience in Europe suggests that a plant which can handle up to 15-20,000 tpa is the smallest scale which will be financially viable as seen in the case study mentioned in Chapter 4.

Using European examples to create the financial model for a centralised AD system, certain assumptions have been made. It is difficult to ascertain whether these assumptions are wholly transferable to a South African case study. However seeing as European examples are the only large scale AD plants in current operation (e.g.Tilburg, Netherlands and EcoPark II, Barcelona, both of these deal with organic waste in excess of 40 000 tons per annum as seen in the case study mentioned in Chapter 4) that divulge the information necessary for this study, these estimates will have to suffice.

i.) CAPEX Assumptions for Centralised Anaerobic Digestion: The CAPEX assumptions in this instance include the capital cost of the technology, a gas holder and the cost of the land required for the facility.

Table 13: CAPEX assumptions for centralised AD financial model

Parameter	Level	Reason for Choice
Capital Cost of Technology including gas holder	R100 million for a facility with an output of between 1 and 3 MW of electricity. R750 000 is set aside for the gas holder	This estimate is based on European prices, an average between the facilities in the Netherlands and Barcelona. Information was also received from a company in Europe that builds AD (Eisenmann, personal interview, 2010). The six-tenths factor rule is once again applicable here. The price of the gas holder is based on European prices (AGAMA, 2006).
Land Requirement for site	3 hectares	The EcoPark facility in Barcelona consists of AD technology able to process 125 000 tpa of organic waste. The site is 10 hectares in size but includes all infrastructure needed for treatment of organic waste including separation. There is necessary infrastructure that must be built around the AD facility. This will include administration offices, roads and the necessary space for the stockpiling of a sufficient amount of waste. 3 hectares will be sufficient for this size facility (43 000 tpa) and also takes into consideration the possibility of site expansion in the future. (Cohen, 2005).

ii.) OPEX Assumptions for Centralised Anaerobic Digestion: The operating costs for the anaerobic digestion facility have been divided up between labour, monitoring, maintenance, waste management, disposal of facility rejections and provision for contingencies. Each of these, barring provision for contingencies, will only begin to be accounted for in the first year of operations, year 5 and have been adjusted at the annual inflation rate of 5% from year 0. Many of these estimates have been gathered through conversation with industry experts, anaerobic digester companies in Europe and literature found on facilities in the Netherlands and Barcelona (Cohen, 2005: 35).

Table 14: Operating cost assumptions for centralised AD financial model (in 2010 Rands)

Parameter	Level	Reason for choice
Labour	R4 million	An operator working at a facility of this size would be paid €30 000 per annum. It is estimated that the facility would require 16 – 20 operatives spread over 4 shifts working 7 days a week (Eisenmann, personal interview, 2010). The R4 million is an estimate that is lower than the European salary quoted above and has been adjusted for South African labour.
Monitoring	R480 000	AD requires that the biogas and other relevant gases that are a result of the process be monitored at all times. Gas analysers that are in place will carry out this function and are fully automated. The only cost will be the monthly calibration that is required for each analyser, at R10 000 per analyser per month (Endress & Hauser, personal interview, 2010). For centralised AD there are 4 analysers required to monitor methane, carbon dioxide, hydrogen sulphide and hydrogen. All of these need to be monitored under the emission standards set by the European Union. It is these standards that have been used in the development of South Africa's own Clean Air Act, which will be promulgated in the coming months (Eisenmann, personal interview, 2010)
Maintenance	R8 million	Maintenance is estimated at 8% of capital cost of the technology. This could be as high as 10 - 12% because of the need for controls and the renewal of feedstock that is required roughly every thirty days to maintain an efficient and optimally operating system of this size (Purser, personal interview, 2010). This estimate falls in line with estimates given by AD manufacturers in Europe including Valorga and Eisenmann.
Waste Management	R250 000	As much of the waste would have treated in the mechanical handling system or source separated before being processed in the AD facility, this assumption is a provision given to the waste that will be on site waiting for treatment (Eisenmann, personal interview, 2010).
Disposal of Facility	R1 million	Facility rejections are a major challenge facing an AD operation. The quality of feedstock is vital to the type of output that one wants to achieve from AD.

Rejections		Therefore if a certain component of feedstock is not of good quality it will need to be disposed of. This would mean sorting and transfer of this waste away from the AD facility. At Barcelona's Valorga facility, between 6% and 8% of feedstock is rejected. R1 000 000 represents roughly 4% of feedstock rejections for a centralised AD facility in Cape Town (Cohen, 2005).
Provision for Contingencies	R3 million	Contingencies act as a buffer in plans to enable response to any change and risk that occurs. Contingencies are essential and are not a sign of poor planning. Most important is the degree of contingency that is built in and how it is allocated (Netwon, 2005: 115). This number is not accounted for during year 0 and year 1. In years 3 and 4 contingencies are estimated at 5% of CAPEX of those years respectively as additional contingencies may be required during the building of the facility. In the first year of operations, contingencies reverts back to R3 million per annum (Purser, personal interview, 2010).

iii.) Size of facility: For the centralised AD scenario it has been assumed that an amount of 43000 tpa of organic feedstock will be treated. This can either be received from source separation or from the organic component that is sorted at the mechanical handling system. Currently, the organic component of Cape Town's solid waste sits at 47%. The estimate of 43000 tpa treated in a centralised AD is therefore relatively small in relation to the 47% total (1 000 000 tpa). However, if one looks at the EcoPark II facility in Barcelona, it currently treats 120 000 tpa spread over three digesters of 4300m^3 volume per digester. Therefore the 43000 tpa for a stand-alone AD facility is very much in line with European case studies (Verma, 2002: 35).

An AD plant processing between 40 000 and 45 000 tonnes results in a total amount of 14700 MWh per annum of energy can be yielded. There is also an option to use the biogas produced for other applications aside from electricity generation. With a yield of 1.6 million Nm^3 per annum, this biogas can be upgraded to pipeline natural gas quality for use as a renewable natural gas. This upgraded gas may also be used for residential heating and as vehicle fuel. This is however only possible if the correct infrastructure is in place. This is, however, a consideration decision makers must not rule out.

There is also the matter of the residual digestate that is a by-product of the AD process. If untreated, it is useless and would be sent to landfill. However, if a post-treatment plant (where mixing, screening and sorting of residual feedstock takes place, followed by treatment to establish commercial quality compost) is put in place, the digestate can be treated to fertiliser quality and can then be sold on to farmers or commercial ventures. A facility handling 43000 tpa of organic waste will produce approximately 18000 tonnes of digestate annually.

5.3.5 Assumptions for the Decentralised Anaerobic Digestion Financial Model

In the urban areas of low- and middle-income countries decentralized anaerobic digestion is a promising technology to handle the large organic fraction of the MSW with the additional benefit of producing biogas that can be used for fuel or electricity generation as well as fertilizer. Decentralised AD can be installed in the urban environment, rural areas and also farms and small holdings. The advantage of implementing a decentralised system is that the capital cost is much smaller with the same benefits. Decentralised AD can also target areas that have a greater percentage of organic waste and therefore transport costs are cut down by not having to transport organics to a centralised facility.

For the purposes of this study, data has been collected from a decentralised AD facility built by AGAMA Energy in Cape Town. The digester in question is a 280 m^3 facility consisting of a screening house and a hydraulic fixed slab digester. This type of facility is a non stirred reactor. This means that there is a sludge component and it is designed with a sludge removal pipe which will be opened every 6 months or so and mixed on beds into compost. There is also liquid effluent which can be fed to an aquaculture farm where algae/weed grown from the nutrient rich liquid is fed to farm fish. For this reason this facility does not require a post –treatment plant for digestate, but at the same time loses the income stream that this generates. To carry out comparison to the other large-scale technologies in terms of volume processed, the decentralised model will include 30 to 40 facilities that would be built in optimal locations around the City.

General assumptions of decentralised anaerobic digestion financial model

Generated incomes from electricity sales, landfill airspace savings and avoided emissions were used to carry out the financial analysis necessary to calculate the desired financial indicators. It is also assumed that there is annual inflation of 5%. The project lifespan of the decentralised AD facility is 13 years, in line with interviews with AGAMA Energy. These general assumptions can be found in Appendix H.

i.) CAPEX Assumptions for Decentralised Anaerobic Digestion: CAPEX assumptions for the decentralised anaerobic digestion model include the capital cost of the technology and the amount needed to construct the digester. Land requirements for the site are also included here.

Table 15: CAPEX assumptions for decentralised AD financial model

Parameter	Level	Reason for Choice
Capital Cost and Construction of Technology	Estimated at R1.4 million for a facility 945 tonnes of waste per annum	This estimate is based on information received from AGAMA Energy. This amount includes construction and capital cost. The six-tenths factor rule is once again applied here (Gets, personal interview, 2010).
Land Requirement for site	0.4 hectares (1 acre)	The footprint of the digester is 14.5m x 7.5m (109m^2) but there is also a screen house, sludge beds and the effluent aquaculture which all cover a combined area of about 2000m^2. 1 acre is based on information received from Gets (personal interview, 2010).

ii.) OPEX Assumptions for Decentralised Anaerobic Digestion: The operating costs for the decentralised anaerobic digestion facility are difficult to quantify. Instead, estimates are said to be between 3% and 7% of capital cost. The labour and maintenance operating cost will only begin to be accounted for in the first year of operations, year 2 and has been adjusted at the annual inflation rate of 5% from year 0. These estimates have been made through conversation with AGAMA Energy, who themselves estimate operating costs for a facility of this size to be in the region of R100 000 per year. There is a sludge component and it is designed with a sludge removal pipe which will be opened every 6 months and mixed on beds into compost (Gets, personal interview, 2010)

Table 16: Operating cost assumptions for decentralised AD financial model (in 2010 Rands)

Parameter	Level	Reason for choice
Labour & Maintenance	R100 000	Operating costs are estimated between 3% and 7% of capital expense. Specific details for this size facility are hard to come by. A majority of the R100 000 will be spent on labour that is required to gather, store & load feedstock, keep pipes free flowing and to remove scum. If the plant is of a more technical nature then maintenance costs will increase (Gets, personal interview, 2010)

iii.) Size of facility: For the decentralised AD scenario it has been assumed that an amount of three tons per day of organic waste can be treated. This equates to 945 tons per year if the facility operates for 7 days a week, 45 weeks of the year. This can either be received from source separation or from the organic component that is sorted at the mechanical handling system (AGAMA, 2010). The yield of a 280m^3 facility is 500m^3 of biogas per day or roughly 1000kWh of electricity per day. This equates to a total of 315 000 kWh of electricity per year operating 7 days a week for 45 weeks of the year or 157 500m^3 of biogas operating for the same time (AGAMA, 2010).

5.4 Conclusion

This chapter has provided the assumptions of the four financial models that were created for the analysis portion of this study. Source separation (node1), landfill (node 2) and mechanical handling system (node 4) have not been covered as they are not the focal point of this study. However there are financial values attached to these nodes that will help provide a cumulative evaluation for each pathway and thereby provide a more holistic and rich analysis. The financial values attached to the non-WtE nodes will be discussed in the next chapter, as will the results of the financial models and analysis thereof.

Chapter 6: Waste to Energy Financial Analysis

6.1 Background

This chapter will focus on the analysis of the financial models created in terms of the assumptions of the previous chapter, looking at the performance of each WtE technology in terms of the financial indicators discussed: net present value; return on investment; levelised cost of energy; and levelised cost of waste. Sensitivity analysis of the models will also take place as these help not only the modeller, but future users of the model, to understand the dynamics of a system. Experimenting with a wide range of values can offer insights into behaviour of a system in extreme situations. Discovering that the system behaviour greatly changes for a change in a parameter value can identify a leverage point in the model— a parameter whose specific value can significantly influence the behaviour mode of the system.

Before the analysis of each model takes place, there will be a brief explanation of the financial costs of each of the non-WtE nodes that were mentioned in Chapter 4. These are source separation, landfill and a mechanical handling system. These figures are important as the purpose of this study is to look at the infrastructure needed to support WtE technologies. Therefore knowing the cost of these will enable a complete analysis when looking at the pathways for MSW.

6.2 Non-WtE Node Financial Costs

The non WtE nodes were discussed and described briefly in Chapter 4.

6.2.1 Source Separation (Node 1)

The financial implication of implementing source separation in Cape Town is still under review. However when run by the City, there have been estimates that it costs in the region of R2000/ton of sorted waste collected in the areas where pilot projects have been launched. This is compared to R200/t of regular waste collection with no separation. If these estimates are even vaguely accurate then there is a large financial cost that comes with running a source separation service through the City. It is for this reason that the City has put collection of source separated waste out to contract. There are also roughly 25 companies currently carrying out this service.

There is however still a cost that the City must pay and conversations with the City of Cape Town's Solid Waste Planning division have revealed that source separation in its current form is still expensive and could be more financially viable if it is included in a rate scheme. Even with diversion of waste from landfill, the City stands to lose somewhere between R5 and R15 per household that carries out source separation (Van Vuuren, personal interview, 2010). Industry experts have estimated that the cost to the City to carry out current source separation initiatives is somewhere between R1500 and R2000 per ton (Haider, personal interview, 2010). This will decrease as rate schemes are introduced and this will in future alter the results of this study. However until this happens, this study will assume a cost of R1750/ton for the City to carry out source separation

Financial Impact = R1750/t of waste source separated

6.2.2 Landfill (Node 2)

This study is not considering transport costs and therefore the cost of landfill for the purposes of this study will be represented by the cost of landfill airspace. Experts in waste management and the City of Cape Town estimate this to be to be R303.88/t of waste. This number will rise considerably over the next 3 years (Haider, personal interview, 2010).

Financial Impact = R303.88/t of waste disposed at landfill

6.2.3 Mechanical Handling System (Node 4)

A mechanical handling system that can process municipal solid waste, with a footprint of 600m^2, will cost between R80 and R100 per ton of processed waste. These figures have been adapted from information received from DB Technologies. There is a possibility that this would be higher depending on whether the option of full automation is taken up and also depending on the size of the facility. For this study, less automation will be used and therefore keep the cost of the machinery and the processes down (Beukes, personal interview, 2010). This figure should to be taken with caution as it is site and country specific

Financial Impact = R90/t of waste processed

6.3 Analysis of WtE Financial Model Results

6.3.1 Incineration (Node 3)

The assumptions for a 30 – 40 MW incineration facility were discussed in the previous chapter. This size facility has the capacity to process up to 500 000 tpa of unsorted MSW or treated RDF. If one follows the assumptions mentioned and use them to calculate the net present worth (NPW), return on investment (ROI), levelised cost of electricity and the levelised cost of waste the following results are obtained over the 20 year life cycle of an incineration facility. The full calculations can be found in Appendix G.

Table 17: Financial indicators of incineration model

NPW	ROI	Levelised Cost of Electricity	Levelised Cost of Waste
R1183 million	19.16%	0.90 R/kWh	R303/t

The NPW of an R819 million investment is R1183 million over 20 years and is greater than 0. This positive net present worth indicates that an investment made in an incineration facility of this scale under the assumptions of the previous chapter will result in positive financial benefits over a 20 year period. For a large capital investment the return on this investment is sound at over 19.16%.

The levelised cost of electricity generation from this facility provides further information on the financial feasibility of an incineration facility. In the case of incineration, the levelised cost of electricity of the facility is R 0.90/kWh generated.

Decision makers must however not forget the cost of transmission and distribution. To give examples of these, transmission costs outside the 900km transmission zone (including Cape Town) with a voltage greater than 132kV average between R 0.23/kWh during the low demand season (Sep to May) and R 0.35/kWh during the high demand season (June to August) (Eskom, 2010). These transmission costs would be an additional cost to the levelised cost of electricity and must be considered when looking at financial feasibility of a facility or technology. Distribution costs will also have an impact on financial feasibility. The more infrastructure needed to reach a consumer, the more expensive it becomes, and the higher the average cost of electricity supplied to that customer (Eskom, 2007).

With the addition of transmission and distribution costs to the levelised cost of electricity generation, the selling price of electricity to consumers is between R 1.13/kWh and R 1.25/kWh (R 0.90/kWh for generation added to R 0.23/kWh and R 0.35/kWh for transmission). If one looks at the current consumer price for electricity, the domestic low for the City of Cape Town is R 0.93/kWh. At this price, incineration is not financially viable if one just looks at the electricity that the facility could generate and sell. Incineration does however remain financially viable because of the other income streams that the technology generates, namely income from landfill airspace savings and carbon credits.

The levelised cost of waste management provides an indicator that can be used when looking at a pathway for municipal waste in the following chapter. R303/ton of waste processed is low compared to the other WtE technologies. However the value of this figure will only be shown when evaluated along with the other nodes in its pathway.

Sensitivity Analysis

Sensitivity analysis is a technique for systematically changing parameters in a model to determine the effects of such changes. Three key variables were tested:

1. Amount of waste processed: This variable is linked to all cost variables and also has a significant influence on the amount of electricity that is generated during the incineration process. For the base scenario, 500 000 tons per annum was used. For the sensitivity analysis, lowest and highest scenarios were run, with two further variables in between.

Table 18: Sensitivity analysis of the amount of waste processed for incineration

	Amount of waste Processed (tpa)	Net Present Worth (Rmil)	ROI	Levelised Cost of Electricity (R/kWh)	Levelised Cost of Waste (R/ton)
Lowest	100 000	691	48%	1.04	348
Low	300 000	931	24%	0.94	315
Base	500 000	1183	19.16%	0.90	303
High	700 000	1439	17%	0.88	295
Highest	1000 000	1832	16%	0.85	287

The sensitivity analysis of the amount of waste processed provides interesting results. The lowest and low variables tested both revealed lower net present worth's than the base case, R691m and R931m respectively, meaning that the project is not as attractive to investors when the facility processes less waste. That is not to say that these NPW's are not attractive, they are just less so than facilities processing more waste.

The ROI, however, was substantially higher than the base scenario, especially with the lowest scenario of 100 000 tonnes. This scenario results in a ROI of 48%. This could be because the decrease in waste processed results in a decrease in both CAPEX and OPEX. This also results in a decrease in the amount of electricity generated. However the electricity price is still high and this, coupled with the other income streams, results in a more favourable outcome over the lower costs and therefore a very high ROI over 20 years. On the flipside, the levelised cost of energy was higher for the lower parameters, at R 1.04 and R0.94 respectively, meaning the cost of producing the electricity increased when the amount of waste processed decreased.

The high and highest variables reflected improved net present worths, of R1439m and R1832m but lower ROI percentages of 17% and 16% respectively. This indicates that although the investments are still extremely favourable in terms of NPW, as waste processed increases, the costs become progressively higher and the income generated is not sufficient to offset these higher costs. The only favourable result is that the levelised cost of energy is lower for both of these variables than the base scenario. However, these are negligible at R 0.88 for the higher mid range and R 0.85 for the maximum, a difference of R 0.02 and R 0.05 to the base scenario.

The levelised cost of waste followed a similar trend to the levelised cost of energy. If less waste is processed, the cost of processing a ton of waste increases. The lowest scenario's result of R348/ton shows that even if less waste is processed, the costs of the facility mean that it becomes even more expensive to process a ton of waste. When the amount processed increased significantly, as in the case of the highest scenario, the levelised cost of waste decreased to R287/ton. This is only a R15 difference to the base scenario and therefore shows that the significant increase of the maximum scenario to one million tons processed does not result in a large decrease in the cost of processing a ton of waste.

Therefore an increase in waste processed does not result in significant financial benefits. However, smaller incineration facilities may provide a better financial reward for a smaller capital outlay, at the expense of a higher levelised cost of energy and waste.

2. Selling price of electricity: One of the main reasons for initiating this study was to create renewable electricity that could be sold to electricity distributors, thereby decreasing their dependence on fossil fuel generation. The selling price of electricity is therefore key in determining the success of a facility as it will provide investors with the demand and funds required to keep the facility running. For the base scenario, the electricity price is

R182. 32/MWh of electricity produced. For the sensitivity analysis, lowest and highest scenarios were run, with two further variables in between.

Table 19: Sensitivity analysis of the electricity price of incineration model

	Electricity Price (R/MWh)	Net Present Value (Rmil)	ROI	Levelised Cost of Electricity (R/kWh)	Levelised Cost of Waste (R/ton)
Lowest	R80.00	849	13%	0.90	303
Low	R130.00	1012	16%	0.90	303
Base	R182.32	1183	19.16%	0.90	303
High	R240.00	1370	22%	0.90	303
Highest	R300.00	1565	26%	0.90	303

The sensitivity analysis of the price of electricity showed a more obvious trend. First, the levelised cost of energy and waste are unchanged for each of the sensitivities. This is because they represent the costs of the facility and a change in electricity price will not affect cost, rather revenue. The variables that are affected are the NPW and ROI.

Each financial indicator decreased with a lower electricity price and increased with a higher electricity price. The lower scenarios show a decrease in the NPW to R849m and R1012m respectively and a decrease in the ROI to 13% and 16% respectively. This shows how important a higher electricity price is for the financial viability of the technology. If the price drops, the financial attractiveness of the facility drops. Conversely, higher electricity prices show an increase in the NPW of R1370m and R1565m respectively and an increase in the ROI of 22% and 26% respectively. Once again, this shows that the electricity price has a considerable affect on the financial performance of the technology. The higher the price, the more attractive the project, especially since revenues increase while costs remain the same. If one is investing R819m for a 20 year project, a higher electricity price makes the project financially attractive, especially the highest scenario, with a NPW of R1565m and an ROI of 26%.

This indicates that a lower electricity price hinders the financial performance of this technology, while the higher price favours the performance. The price that electricity is sold to consumers will continue to rise and therefore electricity generators can push their prices higher to distributors to increase their own profits.

3. Income generated from steam sales: Steam from incineration is used for electricity generation, while a large proportion of it is surplus. This steam can either be released into the atmosphere or sold on to an industry that requires it. In Europe, the popular trend is to create CHP (combined heat and power) systems, where there is not only electricity generation, but also the use of steam in a central heating network. Because of Cape Town's climate and the lack of central heating infrastructure found in the City's households, the steam generated by incineration would not be used for this purpose. However if an industry can be identified that would require steam or heat for its operations, this steam will provide a further revenue stream to incineration.

A 30 - 40 MW facility that processes 500 000 tons of MSW per annum will generate 0.33 million tons of steam per annum. If this steam is sold for R70 per ton, also taking into account inflation, there are positive effects on the financial performance of incineration (AGAMA, 2006).

Table 20: Sensitivity analysis of revenue generated from steam sales for incineration

	NPW	ROI	Levelised Cost of Electricity	Levelised Cost of Waste
Base Case	R1183 million	19.16%	0.90 R/kWh	R303/t
Base Case with revenue from steam sales	R1212 million	20%	0.90 R/kWh	R303/t

The revenue generated from steam sales results in an increase of the NPW to R1212m and an increase in the ROI to 20%. The levelised costs remain unchanged as they are not affected by revenue streams. What this sensitivity shows is that if investors can find a market for the surplus steam that is generated, it has a positive, if not nominal, effect on the financial performance of incineration.

One must remember that these results are not to be taken on their own. If one is to truly understand the cost of implementing a technology like incineration then one must consider the other stages needed to complete the process. Incineration will form part of a greater integrated waste management structure, and the purpose of this study is to establish which technology, when combined with the other stages required for implementation, results in the optimal outcome for the City of Cape Town's decision makers. This will be discussed in greater detail with an evaluation of the potential pathways for MSW in the next chapter.

6.3.2 Gasification (Node 5)

The assumptions for a 55 – 70 MW gasification facility were discussed in the previous chapter. This size facility has the capacity to process up to 225 000 tpa of treated RDF. If one follows the assumptions mentioned and use them to calculate the net present worth (NPW), return on investment (ROI), levelised cost of electricity and the levelised cost of waste the following results are obtained over the 20 year life cycle of a gasification facility. The full calculations can be found in Appendix H.

Table 21: Financial indicators of gasification model

NPW	ROI	Levelised Cost of Electricity	Levelised Cost of Waste
R756 million	10%	1.33 R/kWh	R977/t

Once again, like the incineration facility, the financial analysis of the gasification facility has revealed positive returns across the three financial indicators. The ROI is lower than incineration at 10%. Also with a capital investment R954 million, only R120m more than incineration, this amount is even more surprising and considerably lower. Even with more electricity being generated, the high CAPEX and considerable OPEX amounts mean that the ROI remains very low. The NPW of R 756 million is once again a positive value. This indicates that a gasification facility operating under the assumptions made in the previous chapter will result in a financial gain for investors over the 20 years of operation.

The levelised cost of electricity generation from this facility provides further information on the financial feasibility of a gasification facility. In the case of gasification, the levelised cost of electricity of the facility is R 1.33/kWh generated.
Decision makers must however not forget the cost of transmission and distribution. To give examples of these, transmission costs outside the 900km transmission zone (including Cape Town) with a voltage greater than 132kV average between R 0.23/kWh during the low demand season (Sep to May) and R 0.35/kWh during the high demand season (June to August) (Eskom, 2010). These

transmission costs would be an additional cost to the levelised cost of electricity and must be considered when looking at financial feasibility of a facility or technology. Distribution costs will also have an impact on financial feasibility. The more infrastructure needed to reach a consumer, the more expensive it becomes, and the higher the average cost of electricity supplied to that customer (Eskom, 2007).

With the addition of transmission and distribution costs to the levelised cost of electricity generation, the selling price of electricity to consumers is between R 1.56/kWh and R 1.68/kWh (R 1.33/kWh for generation added to R 0.23/kWh and R 0.35/kWh for transmission). If one looks at the current consumer price for electricity, the domestic low for the City of Cape Town is R 0.93/kWh. At this price, gasification is not financially viable if one just looks at the electricity that the facility could generate and sell. Gasification does however remain financially viable because of the other income streams that the technology generates, namely income from landfill airspace savings and carbon credits.

The levelised cost of waste management provides an indicator that can be used when looking at a pathway for municipal waste in the following chapter. R977/ton of waste processed is high compared to the other WtE technologies. However the value of this figure will only be realised when evaluated along with the other nodes in its pathway.

Sensitivity Analysis

Sensitivity analysis is a technique for systematically changing parameters in a model to determine the effects of such changes. The variables considered in the sensitivity analysis for gasification were:

1. Amount of waste processed: This variable is linked to all cost variables and also has a significant influence on the amount of electricity that is generated during the gasification process. For the base scenario, 225 000 tons per annum was used. For the sensitivity analysis, lowest and highest scenarios were run, with two further variables in between.

Table 22: Sensitivity analysis of the amount of waste processed for gasification

	Amount of waste Processed (tpa)	Net Present Value (Rmil)	ROI	Levelised Cost of Electricity (R/kWh)	Levelised Cost of Waste (R/ton)
Lowest	50 000	725	9.4%	17.40	2763
Low	130 000	734	9.6%	3.22	1352
Base	225 000	756	10%	1.33	977
High	350 000	781	10.50%	0.7	793
Highest	600 000	834	11.41%	0.34	654

The lowest and low variables tested both revealed lower net present worths than the base case, R725m and R734m respectively, meaning that the project is less attractive to investors when the facility processes less waste. The ROI's were also lower than the base scenario. The decrease in ROI is, however, negligible at less than 1% for the minimum scenario. Therefore decreasing the amount of waste processed for a gasification facility does not increase financial performance. Also this poorer financial performance is enhanced by the considerable increase in the levelised cost of electricity and waste, at R17.40/kWh and R2763/ton for the minimum scenario. These sensitivities show that gasification facilities smaller than the base scenario should not be considered.

Conversely, as more waste is processed in a gasification facility, the financial indicators increase by small amounts. The NPW is higher at R781m and R834m respectively, while the ROI increases to 10.50% and 11.5%. These differences are marginal; however they may influence potential investors in making a decision on which technology to implement. The levelised costs decrease considerably when the amount of waste processed increases. The levelised cost of electricity dropped to an impressive R 0.34/kWh for the maximum scenario. This means that if more waste is processed in a gasification facility, the technology becomes more attractive and also there is more money to be made by investors as the cost of generating one kWh of electricity has dropped from R1.33/kWh to R0.34/kWh. This is much lower than the price that electricity is sold for by distributors.

The levelised cost of waste followed a similar trend to the levelised cost of energy. If less waste is processed, the cost of processing a ton of waste increases. When the amount processed increased significantly, as in the case of the maximum scenario of 600 000 tons, the levelised cost of waste decreased to R793/ton, a difference of R184/ton.

2. Price of electricity: For the base scenario, the electricity price is R182. 32/MWh of electricity produced. For the sensitivity analysis, lowest and highest scenarios were run, with two further variables in between.

Table 23: Sensitivity analysis of the price of electricity of gasification model

	Electricity Price (R/MWh)	Net Present Value (Rmil)	ROI	Levelised Cost of Electricity (R/kWh)	Levelised Cost of Waste (R/ton)
Lowest	R80.00	85.67	Negative 0.04%	1.33	977
Low	R130.00	413	5%	1.33	977
Base	R182.32	756	10%	1.33	977
High	R240.00	1133	16%	1.33	977
Highest	R300.00	1526	22%	1.33	977

The sensitivity analysis of the price of electricity for gasification showed very similar trends to those observed in incineration. With levelised cost of electricity and waste unchanged throughout each scenario, each financial indicator decreased with a lower electricity price and increased with a higher electricity price. A lower NPW and negative ROI were the result of the lowest price scenario, showing once again the importance of a high selling price of electricity. If the price drops, the financial attractiveness of the facility drops. Conversely, higher electricity prices show an increase in the NPW of R1133m and R1526m respectively and an increase in the ROI of 16% and 22% respectively. Once again, this shows that the electricity price has a considerable affect on the financial performance of the technology. The higher the price, the more attractive the project, especially since revenues increase while costs remain the same. This indicates that a lower electricity price hinders the financial performance of this technology, while the higher price favours the performance. This also shows that the electricity price has a greater influence on financial viability that the amount of waste processed. However, if one were to incorporate a higher electricity price with the maximum scenario of waste processed, gasification would be seen as a favourable option.

The price of electricity has a bigger influence the financial performance of gasification than the amount of waste processed. The price of electricity will go up in the future and therefore it is clear that the gasification facilities financial performance will improve.

3. Income generated from steam sales: Gasification generates a large amount of steam when RDF is processed. Some of this steam is used for electricity generation, while a large proportion of it is surplus. This steam can either be released into the atmosphere or sold on to an industry that requires it. In Europe, the popular trend is to create CHP (combined heat and power) systems, where there is not only electricity generation, but also the use of steam a central heating network. Because of Cape Town's climate and the lack of central heating infrastructure found in the City's household, the steam generated by gasification would not be used for this purpose. However if an industry can be identified that would require steam or heat for its operations, this steam will provide a further revenue stream to gasification. A 55 – 70 MW facility that processes 225 000 tons of RDF per annum will generate 1.4 million tons of steam per annum. If this steam is sold for R70 per ton, also taking into account inflation, the effects of the financial performance of gasification are considerable (AGAMA, 2006)

Table 24: Sensitivity analysis of revenue generated from steam sales of gasification

	NPW	ROI	Levelised Cost of Electricity	Levelised Cost of Waste
Base Case	R756 million	10%	1.33 R/kWh	R977/t
Base Case with revenue from steam sales	R1579 million	22%	1.33 R/kWh	R977/t

The revenue generated from steam sales results in more than doubling of the NPW to R1579m and an increase in the ROI to 22%. The levelised costs remain unchanged as they are not affected by revenue streams. What this sensitivity shows is that if investors can find a market for the surplus steam that is generated, it has a significant effect on the financial performance of gasification and makes it an even more attractive option for investors.

One must once again bear in mind these results are still only considering the gasification facility as a stand-alone option. Once the other stages that combine to make up the 'gasification' pathway are considered, it may result in the technology becoming a more favourable option.

6.3.3 Centralised Anaerobic Digestion (Node 6)

The assumptions for a 1 -3 MW centralised anaerobic digestion facility were discussed in the previous chapter. This size facility has the capacity to process up to 43 000 tpa of organic waste from source separation or the wet organic fraction that is created in a mechanical handling system. If one follows the assumptions mentioned and use them to calculate the net present worth (NPW), return on investment (ROI), levelised cost of electricity and levelised cost of waste the following results are obtained over the 20 year life cycle of a centralised anaerobic digestion facility. The full calculations can be found in Appendix I.

Table 25: Financial indicators of the centralised anaerobic digestion model

NPW	ROI	Levelised Cost of Electricity	Levelised Cost of Waste
R143million	17.6%	2.70 R/kWh	R687/t

The financial indicators for the centralised anaerobic digestion model perform well, although one must not get carried away when the technology has a high electricity purchase price of R960/MWh. This is considerably higher than any of the other models and is due to the fact that any anaerobic digestion facility greater than 1MW is eligible for the REFIT assigned to biogas electricity generation. A NPW of R143 million indicates a positive number and therefore on this alone shows that an investment should be made in this project. The ROI is also higher than gasification at 17.6% but lower than that of incineration. This could be a result of low CAPEX costs coupled with considerable electricity generation. All of this aside, these figures are still positive and point towards this waste-to-energy technology as being a viable option for investment.

The levelised cost of electricity indicates that this option is one that does not perform as well as the thermal technologies. In this instance the value is R 2.70/kWh. This is considerably higher than the previous models. Decision makers must however not forget the cost of transmission and distribution. To give examples of these, transmission costs outside the 900km transmission zone (including Cape Town) with a voltage greater than 132kV average between R 0.23/kWh during the low demand season (Sep to May) and R 0.35/kWh during the high demand season (June to August) (Eskom, 2010). These transmission costs would be an additional cost to the levelised cost of electricity and must be considered when looking at financial feasibility of a facility or technology. Distribution costs will also have an impact on financial feasibility. The more infrastructure needed to reach a consumer, the more expensive it becomes, and the higher the average cost of electricity supplied to that customer (Eskom, 2007).

With the addition of transmission and distribution costs to the levelised cost of electricity generation, the selling price of electricity to consumers is between R 2.93/kWh and R 3.05/kWh (R 2.70/kWh for generation added to R 0.23/kWh and R 0.35/kWh for transmission). If one looks at the current consumer price for electricity, the domestic low for the City of Cape Town is R 0.93/kWh. Centralised AD is therefore higher than this and therefore for this ir to remain financially attractive, it relies on a high electricity price through REFIT as well as the other income streams, including the sale of carbon credits, the benefit of landfill airspace savings and the sale of digestate.

The levelised cost of waste provides an indicator that can be used when looking at a pathway for municipal waste in the following chapter. R687/ton of waste processed is higher than incineration but lower than gasification. However the value of this figure will only be realised when evaluated along with the other nodes in its pathway.

Sensitivity Analysis

Sensitivity analysis is a technique for systematically changing parameters in a model to determine the effects of such changes. The variables considered in the sensitivity analysis for centralised anaerobic digestion were:

1. Amount of waste processed: This variable is linked to all cost variables and also has a significant influence on the amount of electricity that is generated during the centralised anaerobic digestion process. For the base scenario, 43 000 tons per annum was used. For the sensitivity analysis, lowest and highest scenarios were run, with two further variables in between.

Table 26: Sensitivity analysis of the amount of waste processed of the centralised AD model

	Amount of waste Processed (tpa)	Net Present Worth (Rmil)	ROI	Levelised Cost of Electricity (R/kWh)	Levelised Cost of Waste (R/ton)
Lowest	10 000	66	18%	3.76	946
Low	25 000	99	16%	3.01	766
Base	43 000	143	17.6%	2.70	687
High	65 000	201	20%	2.51	640
Highest	100 000	295	23%	2.34	600

The variables tested in this sensitivity analysis show that there are variable results in financial performance if the current centralised facility were to deal with less waste. The NPW decreases to R66m and R99m respectively, while the ROI increases for the lowest scenario and decreases for the low scenario. This shows that the lowest scenario shows high returns on a lower amount invested, while the low variable is not as attractive financially when processing more waste.

The only downside is that the levelised cost of energy is at a high of R 3.76/kWh for the minimum scenario. This is perhaps the only factor that counts against a smaller centralised unit.

The higher variables performed considerably better than the base variable financially, with NPW increasing to R201m and R295m respectively and ROI increasing to 20% and 23% for the higher mid range and maximum scenarios. The levelised costs of electricity and waste are also improved with increased waste processing. This could be as a result of higher electricity generation and therefore higher revenue, coupled with small increases in cost that are offset by the increased waste being processed.

The levelised cost of waste followed a similar trend to the levelised cost of energy. If less waste is processed, the cost of processing a ton of waste increases. When the amount processed increased significantly, as in the case of the maximum scenario, the levelised cost of waste decreased to a much lower figure.

This sensitivity analysis shows that when considering centralised anaerobic digestion, larger facilities may be in the investor's best interest as it looks to perform better.

2. Price of electricity: One of the main reasons for initiating this study was to create renewable electricity that could be sold to electricity distributors, thereby decreasing their dependence on fossil fuel generation. The price of electricity is therefore key in determining the success of a facility as it will provide investors with the demand and funds required to keep the facility running. For the base scenario, the electricity price is R960.00/MWh of electricity produced, based on the REFIT. For the sensitivity analysis, lowest and highest scenarios were run, with two further variables in between.

Table 27: Sensitivity analysis of electricity price of centralised AD model

	Electricity Price (R/MWh)	Net Present Value (Rmil)	ROI	Levelised Cost of Electricity (R/kWh)	Levelised Cost of Waste (R/ton)
Lowest	R200.00	98	12%	2.70	687
Low	R500.00	116	14%	2.70	687
Base	R960.00	143	17.6%	2.70	687
High	R1200.00	158	19%	2.70	687
Highest	R1500.00	176	22%	2.70	687

With levelised cost of energy and waste unchanged for each scenario, the variances in prices for this sensitivity analysis once again show similar trends to the thermal technologies. The REFIT base price of R960/MWh provides this scenario with the revenue stream required to perform to an adequate financial level: when the price drops to the minimum and lower mid range variables, the NPW drops to R98m and R116 m while the ROI drops to 12% and 14%. This means that for a centralised AD facility to remain financially sound, the feed-in tariff provided by NERSA must remain high. In other words, the price that a distributor will pay for the electricity generated by a centralised AD facility must continue to rise. If there is uncertainty as to the price trends in the future, then this may influence investors on whether to invest in this technology or not. This is shown by the higher mid range and maximum scenarios, showing increased NPW of R158m and R176m and increased ROI of 19% and 22%.

If NERSA decided to drop this tariff considerably, the financial viability of centralised AD comes into question. For now, however, the option remains a good one.

In terms of financial performance, the centralised anaerobic digestion model as a stand-alone technology performs to a level that provides positive NPW and ROI and therefore could be attractive to an investor. This may improve when one considers it as part of an integrated waste solution. However, the initial size estimates of the centralised plant may need to be rethought, as it seems that a larger centralised AD facility will improve financial performance considerably.

6.3.4 Decentralised Anaerobic Digestion (Node 7)

The assumptions for a 40 - 50 kW decentralised anaerobic digestion facility were discussed in the previous chapter. This size facility has the capacity to process up to 945 tpa of organic waste from source separation or the wet organic fraction that is created in a mechanical handling system. If one follows the assumptions mentioned and use them to calculate the net present worth (NPW), return on investment (ROI), levelised cost of electricity and levelised cost of waste the following results are obtained over the 13 year life cycle of a decentralised anaerobic digestion facility. The full calculations can be found in Appendix J.

Table 28: Financial indicators of decentralised anaerobic digestion model

NPW	ROI	Levelised Cost of Electricity	Levelised Cost of Waste
R 1 526 958	14%	1.49 R/kWh	R355/t

The financial indicators for the decentralised anaerobic digestion model do not perform as well as the centralised model. One must consider that there is a smaller capital investment for this facility but a strength of this scenario. It has been included as an option because it allows decision makers to pinpoint which areas have a higher percentage of organic waste and would therefore benefit from such a facility. With a capital outlay of R1.4 million and following the assumptions covered in the previous chapter, the following results were obtained. A ROI of 14% is lower than incineration and centralised AD but outperforms gasification. However for a modest investment of R1.4 million, this number is not disappointing. Finally, the NPW of R 1 526 958 is a positive result and therefore this facility should be considered for investment.

Under the assumptions made in the previous chapter and the current investment required, the NPW indicates that the decentralised AD facility is one that should be considered for implementation.

These figures may also improve if there is a widespread uptake of these facilities throughout the City of Cape Town. The economies of scale may become more favourable with the implementation of more decentralised AD facilities as was discussed in the previous chapter. With 30 – 40 facilities implemented, decentralised AD is an option that needs to be considered by decision makers.

The levelised cost of energy also indicates that the decentralised model produces strong financial outcomes. In this instance it is R 1.49/kWh which performs worse than gasification and incineration. However it is lower than the centralised AD model and therefore investors will still feel pleased with this outcome. Decision makers must however not forget the cost of transmission and distribution. To give examples of these, transmission costs outside the 900km transmission zone (including Cape Town) with a voltage greater than 132kV average between R 0.23/kWh during the low demand season (Sep to May) and R 0.35/kWh during the high demand season (June to August) (Eskom, 2010). These transmission costs would be an additional cost to the levelised cost of electricity and must be considered when looking at financial feasibility of a facility or technology. Distribution costs will also have an impact on financial feasibility. The more infrastructure needed to reach a consumer, the more expensive it becomes, and the higher the average cost of electricity supplied to that customer (Eskom, 2007).

With the addition of transmission and distribution costs to the levelised cost of electricity generation, the selling price of electricity to consumers is between R 1.72/kWh and R 1.84/kWh (R 1.49/kWh for generation added to R 0.23/kWh and R 0.35/kWh for transmission). If one looks at the current consumer price for electricity, the domestic low for the City of Cape Town is R 0.93/kWh. Decentralised AD is therefore higher than this and for it to remain financially attractive, it relies on other income streams, including the sale of carbon credits and the benefit of landfill airspace savings.

The levelised cost of waste provides an indicator that can be used when looking at a pathway for municipal waste in the following chapter. R355/ton of waste processed is the second lowest levelised cost of waste figure of the four technologies and therefore performs strongly in this category. However the value of this figure will only be realised when evaluated along with the other nodes in its pathway.

Sensitivity Analysis

Sensitivity analysis is a technique for systematically changing parameters in a model to determine the effects of such changes. The variables considered in the sensitivity analysis for decentralised anaerobic digestion were:

1. Amount of waste processed: This variable is linked to all cost variables and also has a significant influence on the amount of electricity that is generated during the decentralised anaerobic digestion process. For the base scenario, 945 tons per annum was used. For the sensitivity analysis, lowest and highest scenarios were run, with two further variables in between.

Table 29: Sensitivity analysis of amount of waste processed of decentralised AD model

	Amount of waste Processed (tpa)	Net Present Value (R)	ROI	Levelised Cost of Electricity (R/kWh)	Levelised Cost of Waste (R/ton)
Lowest	500	611 898	7.5%	3.53	444
Low	750	1 117 927	11%	2.03	384
Base	945	1 526 958	14%	1.49	355
High	1200	2 074 552	16%	1.09	328
Highest	1500	2 732 125	19%	0.81	307

The sensitivity analysis of the amount of waste processed for decentralised AD shows that a larger decentralised AD facility will provide improved financial performance and will also result in a significant drop in the levelised cost of electricity and waste. If one considers the highest variable of 1500 tons per annum, this results in a capital outlay of a little under R 2 million, only R 600 000 more than the base case. With this increase in investment, the NPW increases to R 2 732 125 and the ROI increases to 19%. The other impressive point is the drop in the levelised cost of energy to only R 0.81/kWh. This would make decentralised AD the cheapest option when looking at the cost to generate electricity.

The levelised cost of waste followed a similar trend to the levelised cost of energy. If less waste is processed, the cost of processing a ton of waste increases to R444/ton and

R384/ton respectively. When the amount processed increased significantly, as in the case of the maximum scenario, the levelised cost of waste decreased to R307/ton, an even more favourable scenario. The consideration that must be taken here is that if decentralised AD is a possibility for decision makers, then larger facilities than the base case will provide optimal financial returns.

2. Price of electricity: One of the main reasons for initiating this study was to create renewable electricity that could be sold to electricity distributors, thereby decreasing their dependence on fossil fuel generation. The price of electricity is therefore key in determining the success of a facility as it will provide investors with the demand and funds required to keep the facility running. For the base scenario, the electricity price is R 0.18/kWh of electricity produced. For the sensitivity analysis, lowest and highest scenarios were run, with two further variables in between.

Table 30: Sensitivity analysis of electricity price of decentralised AD model

	Electricity Price (R/kWh)	Net Present Value (R)	ROI	Levelised Cost of Electricity (R/kWh)	Levelised Cost of Waste (R/ton)
Lowest	R 0.05	1 194 316	10%	1.49	355
Low	R 0.10	1 322 255	12%	1.49	355
Base	R 0.18	1 526 958	14%	1.49	355
High	R 0.25	1 706 074	15%	1.49	355
Highest	R 0.35	1 961 953	18%	1.49	355

The sensitivity analysis of the price of electricity for decentralised anaerobic digestion showed very similar trends to the previous three models. With levelised cost of energy and waste unchanged for each scenario, each financial indicator decreased with a lower electricity price and increased with a higher electricity price. The lowest scenario results in a NPW of R 1 194 316 and a ROI of 10%. The highest scenario results in a NPW of R 1 961 953 and a ROI of 18%. This shows that the increase in price improves financial performance of the decentralised AD technology.

The price of electricity has a smaller influence on the financial performance than the amount of waste processed does. For increased financial performance, decision makers should consider implementing decentralised AD facilities that can process more waste than the base scenario discussed here.

The decentralised anaerobic digestion financial model performs well and would be an attractive option for investors, especially with such a small amount of investment needed. However, once again it must not be forgotten that the performance of this scenario may not continue to be optimal once it is integrated in a pathway. There are still considerable steps that need to be taken to ensure that the organic waste reaches a decentralised facility, and to disregard these steps will be detrimental to decision makers making an informed and justified conclusion as to which technology option is the most viable.

6.4 Conclusion

This chapter has shown, through analysis of the results of the financial models of each technology, that each of these technologies could be implemented when looking at their financial performances. NPW is not used to compare technologies as there are large disparities between the investments and the size of each technology. Rather ROI, levelised cost of electricity and levelised cost of waste are used. Table 36 shows that incineration is the strongest individual technology performer, with the highest ROI and the lowest levelised cost of electricity and levelised cost of waste. Gasification performs moderately well but has a lower ROI. Gasification also has the second lowest levelised cost of electricity but the highest levelised cost of waste.

Table 31: Summary of financial analysis of all WtE technologies

	ROI	**Levelised cost of electricity**	**Levelised cost of waste**
Incineration	19%	0.90 R/kWh	R303/t
Decentralised AD	14%	1.49 R/kWh	R355/t
Centralised AD	17.6%	2.70 R/kWh	R687/t
Gasification	10%	1.33 R/kWh	R977/t

The two non-thermal technologies have their own pros and cons. Centralised AD performs better than gasification in terms of ROI and levelised cost of waste but is weaker when looking at levelised cost of electricity. It has the highest levelised cost of energy but its levelised cost of waste is considerably lower than gasification. The sensitivity analysis showed that this option will perform better if it were a larger facility processing up to 100 000 tons per annum.

Decentralised anaerobic digestion continues to impress. The ROI performs positively, although lower than the other technologies. The promising indicators were the levelised cost of waste and energy. The levelised cost of energy, although more than the two thermal technologies, is lower than centralised AD. The levelised cost of waste is the second lowest of all technologies, an impressive result for a small facility. There may even be scope for improved performance if there are numerous facilities established around Cape Town. This could improve again if these facilities are bigger than the base scenario discussed. One must also bear in mind that the transport costs associated are much lower or non-existent for this scenario as waste is processed on site and this could lead to further enhancement and viability of this technology as a standalone option.

One must remember for each of these models that as much as financial indicators are important and perhaps play the strongest hand in determining whether a technology is implemented or not, the technologies must not be considered in isolation. The purpose of the study is to establish which technology is most effective when integrated into a waste management system that provides the infrastructure needed for successful WtE implementation. The following chapter will evaluate the pathways of MSW that will lead to the implementation of a WtE facility.

Chapter 7: Pathway Evaluation

7.1 Background

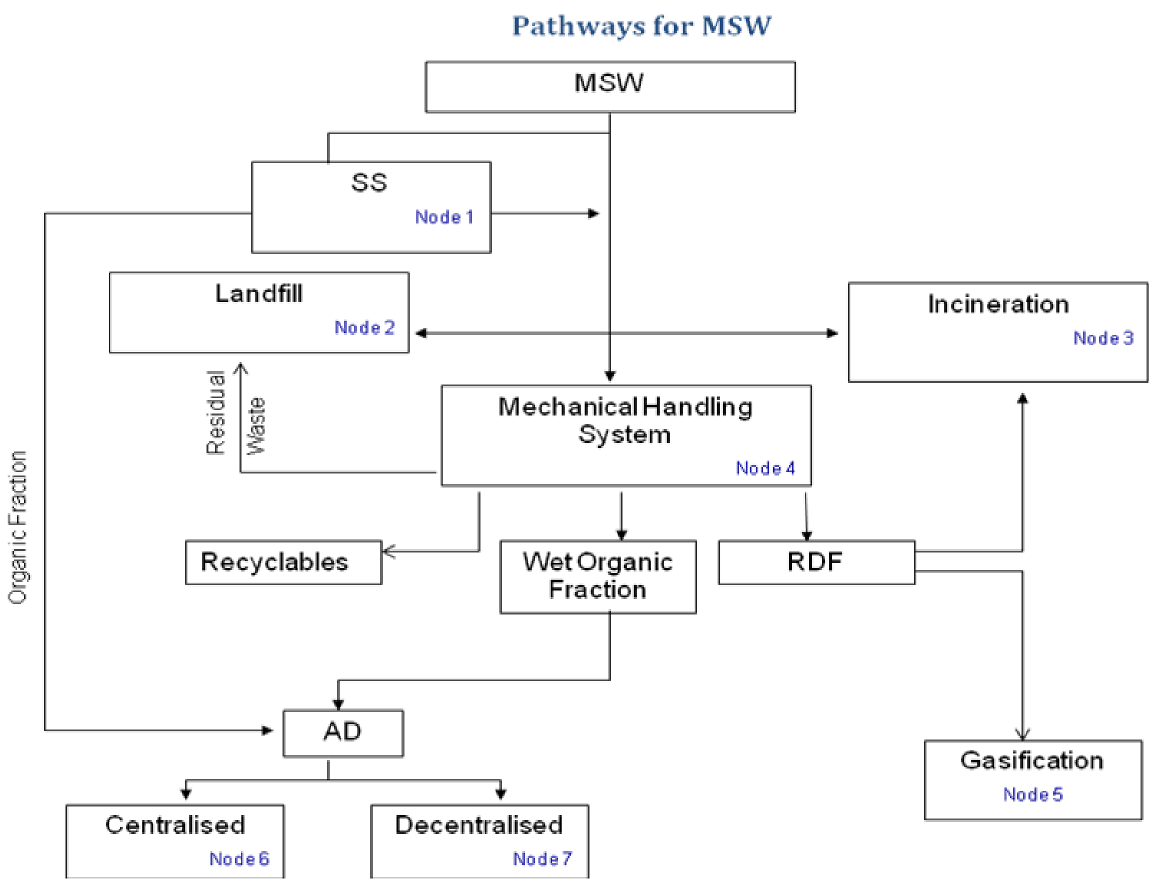
This chapter provides the evaluation of the pathways for municipal solid waste that could lead to a particular waste-to-energy technology being implemented. There will be 6 pathways evaluated that will give an insight into the overall performance of each waste-to-energy technology when combined with the stages and measures needed for successful implementation. This will include as business-as-usual scenario, looking at the impacts of MSW going to landfill, as it is now. The other pathways will each cover what can be seen as the best option for the potential implementation of a WtE technology.

7.2 Evaluation of Pathways for MSW

Figure 8 has been repeated in order to provide easy access to the reader. This also acts as a reminder as to what the pathways for MSW are.

Figure 8: Pathways for municipal solid waste

Adapted from Kiser and Burton, 1992



One key assumption made here which has not been explored previously relates to the cost to transport one tonne of waste. In personal correspondence with a waste expert in the City (Haider, personal interview, 2010), it has been estimated that it costs the City R600 to dispose of one tonne of waste. Landfill airspace is R303.88/t of waste at landfill (which includes the cost to recover capital, the incremental cost of replacement based on forward costing, and landfill rehabilitation). Therefore the transport and collection costs assumed for one tonne of waste are R296.12/t. All other financial indicators have been already been discussed in Chapter 6.

7.2.1 Pathway 1

It is important to establish a business-as-usual scenario, a scenario that is currently being used by the City of Cape Town (Pathway 1). This will provide a good comparative base with which to compare other pathways that will be evaluated. In this instance the business-as-usual scenario will be that of sending 1 tonne of MSW straight to landfill. The cumulative financial impact of this pathway is R600/t, as discussed previously.

Table 32: Financial impact of pathway 1

Node	**Transport**	**2 (waste to landfill)**	**Cost/ tonne waste generated**
Tonnage	1 tonne	1 tonne	-
Cost	R296.12	R303.88	R600/t

7.2.2 Pathway 2

Pathway 2 is comprised of source separation, incineration and landfill. For the City of Cape Town, it has been shown that 32% of one tonne of waste consists of recyclable material. The remaining 68% is suitable for incineration (AGAMA, 2006). This information can be found in section section 5.3.2 sub-section (iii). Initially 320kg of recyclables are separated at source. The resultant 680kg are transported to an incineration facility where it is processed. 20% of the 680kg ends up as ash at the end of the incineration process and is subsequently sent to landfill. In this instance for every tonne processed 136kg will be sent to landfill as ash. The pathway results in over half a tonne of waste being diverted from landfill at a cost of R1008.16/t.

Table 33: Financial Impact of pathway 2

Node	1 (source separation)	Transport	3 (incineration)	2 (ash to landfill)	Cost/ tonne waste generated (figure is rounded)
Tonnage	320kg	680kg	680kg	136kg	-
Cost	R560	R201.36	R205.80	R41	R1008/t

7.2.3 Pathway 3

Pathway 3 includes a mechanical handling system, gasification and residual waste going to landfill. Initially one tonne of MSW is transported to a mechanical handling system. For the City of Cape Town, it has been shown that 32% of one tonne of waste consists of recyclable material. The remaining 68% is suitable for treatment, with 47% of this accounted for by organic waste (AGAMA, 2006). This information can be found in section section 5.3.3 sub-section (iii).It is assumed for pathway 3 that there is a potential recyclable component of 340kg/t of waste going to the mechanical handling system. Stage one of the mechanical handling system process removes metals and inert fractions such as glass. Metals account for 2% of total waste or 20 kg per tonne. With a selling price of R0.47/kg, R9.49 is generated from the sale of metals (Tsekoa et al, 2007). Glass accounts for 15% of recyclables (340kg), or 51kg per tonne. At R0.27/kg, R13.77 is generated from the sale of glass (Tsekoa et al, 2007). Total revenue of R23.26 is generated and this is a negative number in table 35 because it is an income stream.

Stage two separates out the wet putrescible fraction that includes garden and food waste. This equates to 470kg and this wet fraction will be sent to landfill as it is not required to produce RDF. The third stage occurs with the coarse fraction being separated and put back into the system. The last stage results in the medium fraction (consisting of paper, card, wood, plastic and textiles) being dried into dense RDF ready for combustion. This equates to 289 kg being processed by gasification. The residual waste of 170kg will be sent to landfill along with the organic waste (470kg). The cumulative cost of this pathway is R838.86/t.

Table 34: Financial Impact of pathway 3

Node	Transport	4 (MHS)	Revenue from recyclable fraction	5 (gasification)	2 (residual waste to landfill)	Cost/ tonne waste generated (figure is rounded)
Tonnage	1 tonne	1 tonne	71kg	289kg	640kg	-
Cost	R296.12	R90	-R23.26	R282	R194	R839/t

7.2.4 Pathway 4

Pathway 4 includes a mechanical handling system, centralised AD and residual waste to landfill. Initially one tonne of MSW is transported to the mechanical handling system. For the City of Cape Town, it has been shown that 32% of one tonne of waste consists of recyclable material. The remaining 68% is suitable for treatment, with 47% of this accounted for by organic waste (AGAMA, 2006). This information can be found in section section 5.3.4 sub-section (iii).It is assumed for pathway 4 that there is a potential recyclable component of 340kg/t of waste going to the mechanical handling system. Stage one of this process removes metals and inert fractions such as glass. Metals account for 2% of total waste or 20 kg per tonne. With a selling price of R0.47/kg, R9.49 is generated from the sale of metals (Tsekoa et al, 2007). Glass accounts for 15% of recyclables (340kg), or 51kg per tonne. At R0.27/kg, R13.77 is generated from the sale of glass (Tsekoa et al, 2007).

Stage two separates out the wet putrescible fraction that includes garden and food waste. This equates to 470kg and this wet fraction will be sent to the anaerobic digester for processing. The third stage occurs with the coarse fraction being separated and put back into the system. Once it is shredded and slurried, the screening process will reject roughly 4% of this organic waste. Therefore of the 470kg, 450kg is processed. The rejected 20kg will be transported to landfill along with the remaining residual waste.

The last stage that would usually convert the medium fraction to RDF is not required here and therefore the recyclable materials can be sold to generate revenue. In this case this includes paper, card and plastic. Paper and card account for 39% of recyclables (340kg) or 132 kg. At R0.27/kg for all paper types, R36 worth of revenue is generated (Tsekoa et al, 2007). Plastic accounts for 15% of recyclables (340kg) or 51kg. At R1.20/kg for all plastic types, R61.20 worth of revenue is generated (Tsekoa et al, 2007). This revenue combined with the revenue from metal and glass sales results in R143.87. This is a negative number in table 36 because it is an income stream.

This leaves 106kg to be sent to landfill, along with the rejected organic waste of 20kg and the residual waste of 170kg. The cumulative cost of this pathway is R678.29/t.

Table 35: Financial Impact of pathway 4

Node	Transport	4 (MHS)	Revenue from recyclable fraction	6 (AD)	2 (residual waste to landfill)	Cost/ tonne waste generated (figure is rounded)
Tonnage	1 tonne	1 tonne	254kg	470kg	296kg	-
Cost	R296.12	R90	-R120.46	R323.03	R89.6	R678/t

7.2.5 Pathway 5

Pathway 5 consists of source separation, decentralised AD and residual waste going to landfill. For the City of Cape Town, it has been shown that 32% of one tonne of waste consists of recyclable material. The remaining 68% is suitable for treatment, with 47% of this accounted for by organic waste (AGAMA, 2006). This information can be found in section section 5.3.5 sub-section (iii).First waste is source separated into recyclables, with a mass of 320kg. 470kg of organic waste is used close to generation at a decentralised AD facility. Once it is shredded and slurried, the screening process will reject roughly 4% of this organic waste. Therefore of the 470kg, 450kg is processed. The rejected 20kg will be transported to landfill along with the remaining residual waste. If this pathway is to be an option, then decision makers will have to implement a considerable number of these smaller digesters to present a financially viable alternative and to make a significant impact on reducing waste management.

Table 36: Financial impact of pathway 5

Node	1 (source separation)	7 (decentralised AD)	Transport	2 (residual waste to landfill)	Cost/ tonne waste generated (figure is rounded)
Tonnage	320kg	450kg	380kg	380kg	-
Cost	R560	R160.50	R113	R115	R949/t

The cumulative cost of pathway 5 is R948.50/t of waste processed. This outperforms pathways 3 and 4. However a large amount of non-organic household and industrial waste will still end up at landfill. This is perhaps not optimal, but there are other benefits associated with a decentralised AD facility that have been mentioned such as its revenue streams and decreasing transport costs for the City.

7.2.6 Pathway 6

The last pathway that will be considered is one tonne of municipal solid waste transported to an incineration facility and the residual ash (200kg) from the incineration process going to landfill. Even though the aim of this study was to not look at WtE technologies in isolation, it gives a rounded evaluation to include this option. This means that some organics and recyclables will end up being processed by the incinerator, an option that goes against the hierarchy of integrated waste management. However, removing the need to process or sort the waste makes pathway 6 a strong performer.

Table 37: Financial impact of pathway 6

Node	Transport	3 (incineration)	2 (ash to landfill)	Cost/ tonne waste generated (figure is rounded)
Tonnage	1 tonne	1 tonne	200kg	-
Cost	R296.12	R303.68	R61	R661/t

With no source separation occurring, every tonne will be incinerated. Incineration results in 20% of the waste processed ending up as ash that would need to be sent to landfill. Therefore 200kg will be sent to landfill. This results in a cumulative cost of R660.80/t of waste processed. This is the lowest of all WtE pathways considered here.

7.3 Conclusion

The pathway analysis that has taken place has revealed some surprising results. Pathway 6, looking at incineration of unsorted MSW came out on top when considering cumulative financial performance of WtE pathways. This pathway does however go against the hierarchy of integrated waste management and therefore some would argue that this counts against it. No WtE pathway was cheaper than the BAU scenario of waste going to landfill. The cost per ton to dispose of waste is used as the main financial indicator to compare pathways. However one must remember that all the pathways aside from the BAU scenario have high revenue streams, generate electricity and decrease the amount of waste that ends up at landfill thereby making them more attractive options.

Table 38: Summary of pathways from most attractive to least attractive

Pathway	Node	Waste Input	Recyclables	Waste to Landfill	Waste processed by WtE technology	Cost/ tonne waste generated (figure is rounded)
1	2	1 tonne	0kg	1000kg	0kg	R600/t
6 (incl. Incineration)	2 + 3	1 tonne	0kg	200kg	1000kg	R661/t
4 (incl. Centralised AD)	2 + 4 + 6	1 tonne	256.4kg	293.6kg	470kg	R678/t
3 (incl. Gasification)	2 + 4 + 5	1 tonne	73.4kg	640kg	289kg	R839/t
5 (incl. Decentralised AD)	1 + 2 + 7	1 tonne	320kg	380kg	450kg	R949/t
2 (incl. incineration	1 + 2 + 3	1 tonne	320kg	136kg	680kg	R1008/t

Peach = most attractive; yellow = attractive; orange = less attractive; red = least attractive

The chapter has highlighted that pathway 6 including incineration and pathway 4 including centralised anaerobic digestion are the most attractive WtE pathways when analysed in terms of the functional unit of one tonne. They are closest in cost/tonne waste generated to pathway 1 but have the added benefits of various revenue streams and decreasing the amount of waste sent to landfill. Pathway 2, which includes source separation and incineration, was the least attractive pathway. It should perhaps not be disregarded though as it does result in recyclables being separated and not lost to an incineration facility. When one considers source separation, it has been discussed that when a rate scheme is eventually introduced by the City for source separation, there will no longer be a cost associated with this to the City. Therefore all pathways that include source separation will improve as no cost will be associated with this node.

Pathway 5, which includes source separation and decentralised AD, was a fair performer, with a large proportion of organic waste treated. Pathway 3, although more attractive that 5 and 2, does result in the largest amount of waste being sent to landfill. This may count against it if it is ever considered.

This study set out to create comparable indicators for each pathway, providing insight into which pathway is the most consistent performer and therefore establishing which pathway is most optimal for implementation and which should not be considered.

Table 40 shows the results of the financial analysis carried out on the WtE technologies in isolation. If one looks at the levelised cost of waste (the cost of processing one tonne of waste through a particular process) it shows that incineration was the strongest performer, followed by decentralised AD, centralised AD and gasification.

Table 39: Summary of levelised cost of waste for WtE technologies in isolation

Waste to energy technology	**Levelised cost of waste**
Incineration	R303/t
Decentralised AD	R355/t
Centralised AD	R687/t
Gasification	R977/t

This is different to the results gained by the pathway analysis. In terms of pathway analysis, pathway 6 including incineration and pathway 4 including centralised AD are the most attractive pathways when analysed in terms of the functional unit of one tonne. Decentralised AD dropped to one of the least favourable pathway options and gasification improved well on its last place. This shows that the pathway approach adds value and proves that analysing a technology in isolation does not always reflect the best option going forward. Rather one must consider these technologies as part of a system thereby obtaining results that are a more realistic reflection of what a technology is capable of.

Chapter 8: Conclusion and Recommendations

8.1 Conclusion

This thesis set out to look at whether waste-to-energy is a viable and feasible technology option to be integrated into the City's waste management programme and that could successfully deal with the City of Cape Town's waste issues going forward and protect the City from its energy vulnerabilities. The hypotheses of the paper were as follows:

Research Hypothesis 1: If waste-to-energy technologies are financially feasible, then those technologies have a potential role to play in an integrated solid waste management system for the City of Cape Town.
Research Hypothesis 2: If WtE is to form part of an ISWM system then pathway analysis is essential in evaluating the feasibility of waste to energy implementation into that ISWM system.

This thesis allowed for successful testing of both hypotheses. Research hypothesis 1 was shown to be true through analysis of financial models and by sensitivities carried out. WtE technologies are financially feasible and subsequently have a role to play in an ISWM system for the City of Cape Town. Research hypothesis 2 showed the benefit of evaluating WtE implementation through pathway analysis: This evident by the change in ranking order and therefore preference for a technology when looking at them isolation compared to technologies in a pathway analysis. Therefore both hypotheses, through testing, have been shown to be true.

Throughout the paper the implications of WtE implementation in a South African context were discussed. First it was established that South Africa currently faces a number of challenges as a result of long-term economic growth. This has lead to increasing pressure on the infrastructure that is in place to service the county's waste and increasing pressure on the country's electricity supplier, Eskom, to continue to deliver sufficient electricity to the entire country. The thesis then went on to provide arguments for and against thermal and non-thermal waste-to-energy technologies and how they can help to tackle the problems that the current national and provincial governments face.

A background into Cape Town's current waste management structure and process was provided and how the current decision makers are trying to establish the best steps to take the city's waste management programme into the future.

A background was then given on the technologies that are considered “waste-to-energy”. Processes were discussed, including optimal operational conditions and the benefits and shortfalls of each technology. Case studies were also discussed, looking specifically at where a particular technology had been implemented around the world. It also addressed the pathways for MSW, looking closely at where WtE would fit into an integrated waste management system if implemented. This provided the necessary background and understanding to the reader for the following sections of the thesis, which discussed the case for implementing waste-to-energy in Cape Town.

The assumptions of the financial models of the WtE technologies followed, giving descriptions of the financial indicators that would form the basis of analysis and also looking at the variables that would be used in each model to calculate these variables. These financial measures provide the thesis with a strong quantitative element that backs up much of the qualitative information mentioned throughout the thesis. It is important to reiterate that the models that were created to carry out this financial analysis demonstrated methodology and should not be used as a rule. The financial analysis of technologies in isolation revealed that incineration is the most attractive option for investors, followed by decentralised AD, centralised AD and gasification. This is on a ranking system based on the cost of processing one tonne of waste.

The results were expected in some instances and surprising in others. The pathway analysis revealed that although no pathway was a more affordable option than waste going to landfill, pathways 6 and 4 showed that they could provide a financially viable option going forward while also processing a large quantity of waste. Each pathway that would result in a waste-to-energy technology being implemented had its own pros and cons in terms of financial performance. The pathway analysis also revealed a change in the ranking order that had been obtained through the financial analysis of technologies in isolation. This shows that the pathway approach adds value and proves that analysing a technology in isolation does not always reflect the best option going forward. Rather one must consider these technologies as part of a system thereby obtaining results that are a more realistic reflection of what a technology is capable of.

This study set out to inform readers of a renewable energy technology that does not garner the same amount of kudos as many of the other ‘glamour’ renewable energy technologies like solar and wind power. The thesis provided information on the benefits and shortcomings of waste-to-energy and how it may provide the solution to the ongoing problem of waste and electricity supply that Cape Town, and South Africa, continues to face. Cape Town provided a good case study to base the report on, as the current decision makers within the municipality are looking at the best options for the city’s future waste management and are also considering the potential that waste has in terms of energy generation, and if avoided, climate change mitigation. The question that was asked at the beginning of the study was whether WtE is financially feasible to be implemented into an ISWM programme for Cape Town. It has been shown through analysis that financially WtE can be implemented and is viable, as technologies in isolation and also as part of pathways for MSW.

It has already been said that there is no panacea to the electricity supply shortage or the waste problem that Cape Town faces. Waste-to-energy technologies, both thermal and non-thermal, are not going to solve Cape Town's problems over night. However, with proper consideration, research, planning and implementation, waste-to-energy may provide an infrastructure and a solution that can alleviate a significant amount of pressure that the City currently and will continue to experience in the future.

8.2 Recommendations

There are three recommendations from this study, covered in more detail below. Recommendation 1 will look at pathway 6 that includes one tonne of waste going to an incineration facility and residual ash going to landfill. The benefit of this pathway is that it does not require infrastructure to be put in place that will separate out recyclables but does see a significant amount of renewable energy generated. Recommendation 2 will look at the added benefit of implementing infrastructure and how this results in a large amount of recyclables being recovered. The benefit of this option is that materials are recovered, less waste goes to landfill and a significant amount of electricity is generated. This option also addresses the hierarchy of waste management. The third recommendation that will be put forward will include pathway 2. In order for the feasibility of these recommendations to be taken beyond desktop research level, it is also recommended that further financial analysis be undertaken for each of these options to a level that would allow investment to take place.

Recommendation 1

Recommendation 1 will look at pathway 6 that includes one tonne of waste going to an incineration facility and residual ash going to landfill. The benefit of this pathway is that it does not require infrastructure to be put in place that will separate out recyclables but does see a significant amount of renewable energy generated. This does of course go against the hierarchy of waste management but if one looks at incineration in isolation, it has the capabilities of processing 500 000 to 1 000 000 tonnes of unsorted MSW per annum. This would result in a significant amount of waste being diverted from landfill and a large amount of renewable energy being generated. Incineration also has a low levelised cost of electricity, meaning that it costs less to produce 1 kWh of electricity than any other technology.

Table 40: Summary of pathway 6

Pathway	Node	Waste Input	Recyclables	Waste to Landfill	Waste processed by WtE technology	Cost/ tonne waste generated
6	2 + 3	1 tonne	0kg	200kg	1000kg	R660.80/t

Table 41: Summary of financial analysis of incineration

	ROI	Levelised cost of electricity	Levelised cost of waste
Incineration	19%	0.90 R/kWh	R302.68/t

Recommendation 2

Recommendation 2 will look at the added benefit of implementing infrastructure and how this results in a large amount of recyclables being recovered. This recommendation includes a mechanical handling system sorting waste combined with a centralised AD facility working alongside a gasification facility. The benefit of this option is that materials are recovered, less waste goes to landfill and a significant amount of electricity is generated. This option also addresses the hierarchy of waste management. As technologies in isolation, gasification and centralised AD were not the strongest performers. However when considered as part of a pathway their performance improved. By integrating these two systems, more materials are recovered and even less waste will end up at landfill, potentially eventually moving towards zero waste.

Sensitivities have also shown that a larger centralised AD facility and larger gasification facility result in higher financial returns and lower levelised costs of electricity and waste. If one were to consider this option then it must also be debated as to the size of the facility. This must therefore be considered once the original facilities have proved their worth.

Table 42: Summary of pathway 3 + pathway 4

Pathway	Node	Waste Input	Recyclables	Waste to Landfill	Waste processed by WtE technology	Cost/ tonne waste generated
3 + 4	2 + 3 + 4 + 5	1 tonne	71kg	200kg	736kg	R1007.12/t

Table 43: Summary of financial analysis of centralised AD and gasification

	ROI	Levelised cost of electricity	Levelised cost of waste
Centralised AD	17.6%	2.70 R/kWh	R687.31/t
Gasification	10%	1.33 R/kWh	R977.45/t

Recommendation 3

The third recommendation that will be put forward will include pathway 2 which includes source separation of recyclables and the incineration of the remaining waste with residual ash going to landfill. Of all the pathways this option sent the least waste to landfill. The City is currently implementing source separation measures but it is proving costly and time consuming. Therefore by implementing it as part of an integrated system that relies somewhat on its success, the City may speed up its current source separation policies and efforts. Until this measure is implemented in an economically sustainable manner, pathway 6 will not be financially attractive. However, once the City implements current plans to introduce a rate scheme, where residents will pay for this service, it will improve financial performance. This will also result in the largest quantity of recyclables being recovered. Incineration is a strong technology in isolation, and if combined with the required infrastructure, will be a suitable long term solution the the waste and energy problems that Cape Town faces.

Table 44: Summary of pathway 6

Pathway	Node	Waste Input	Recyclables	Waste to Landfill	Waste processed by WtE technology	Cost/ tonne waste generated
2	1 + 2 + 3	1 tonne	320kg	136kg	680kg	R1008.16/t

Table 45: Summary of financial analysis of incineration

	ROI	Levelised cost of electricity	Levelised cost of waste
Incineration	19%	0.90 R/kWh	R302.68/t

Decision makers have a number of tough questions to ask and answer when considering whether to implement waste-to-energy as part of an integrated solid waste management strategy. Do they look at the short-term gains that can be made or be more forward thinking and implement a strategy that will improve as time goes on? Pathway 6, an isolated incineration facility, is a strategy that can process a large amount of waste with no real worries about waste treatment or separation. It is also financially strong and therefore investors will see it as a strong contender. It does however not improve recycling initiatives and goes against the hierarchy of waste management which is important to consider when trying to create a sustainable waste management structure.

The other recommendations of the author consider strategies that look more closely at the optimal combinations of required infrastructure and thermal and non-thermal technologies that work efficiently to process large quantities of waste while also generating electricity and other revenue streams. Two combinations have been mentioned above, but this is not to say that these are other the optimal combinations that may reveal themselves as time goes on.

References

A2A, 2009. 'The Brescia Waste-to-Energy Plant'. Available online at: [http://www.a2a.eu/gruppo/cms/a2a/en/company/plants/waste_to_energy/brescia_waste_to_energy/index.html]. Site accessed 12th March 2010

About Cape Town. 2007. Available online at: [http://www.aboutcapetown.com/maps.htm].Site accessed 24th March 2010

AGAMA Energy, 2006. 'Energy Recovery from Municipal Solid Waste in South Africa' prepared for the Department of Science and Technology, Pretoria.

AGAMA, 2009. 'Sustainable Cities: Biogas Energy from Waste' prepared for the South African Cities Network.

ASME, 2009. 'Waste-to-Energy: A Renewable Energy Source from Municipal Solid Waste'. Available online at [http://files.asme.org/Divisions/SWPD/17157.pdf]. Site accessed 18th March 2010.

Beenackers, A. A. C., 1989. 'Gasification and Pyrolysis of Biomass in Europe'. Pyrolysis and Gasification edited by G. L. Ferrero, K. Maniatis, A. Buekens and A. V. Bridgwater. Elsevier Applied Science, London, 1989.

Bellwether Gasification Technologies, 2010. Personal Interview. 24th August 2010

Beukes, K., 2010. Personal Interview. 8th July 2010

Bhada, P., 2010. 'Feasibility of Waste-to-Energy as a key component of Integrated Solid Waste Management in Mumbai, India.' Waste-to-Energy Research and Technology Council (WTERT)

Bontoux, L., 1999. 'The Incineration of Waste in Europe: Issues and Perspectives'. A Report Prepared by IPTS for the Committee for Environment, Public Health and Consumer Protection of the European Parliament. Available online at: [http://www.ejnet.org/dioxin/eur18717en.pdf]. Site accessed 20th April 2010

BP, 2010. ' BP Statistical Review of World Energy'. Available online at: [http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/statistical_review_of_world_energy_full_report_2010.pdf]. Site accessed 13th March 2010

Business Report, 2010. 'Doubt lingers over SA's credit rating.' Available online at: [http://www.busrep.co.za/index.php?fSectionId=552&fArticleId=5428337]. Site accessed 21st April 2010

Centre for Development and Enterprise (CDE), 2008. 'South Africa's Electricity Crisis' prepared for CDE Round Table Number 10, July 2008. Available online at: [http://www.cde.org.za/article.php?a_id=312]. Site accessed 4th April, 2010

City of Cape Town. 2010. Available online at: [http://www.capetown.gov.za/en/Pages/default.aspx]. Site accessed 24th March 2010

City of Cape Town, 2010. 'Think Twice'. Prepared by the City of Cape Town for the Extension of "Think Twice" Door to Door Recycling Services. Availbale online at: [https://www.capetown.gov.za/en/solidwaste/Documents/OtherRecyclingFacilitiesInclThinkTwice.pdf]. Site accessed 7th June 2010

City of Cape Town, 2006. 'Integrated Waste Management (IWM) Policy.' Available online at [http://www.capetown.gov.za/en/solidwaste/Documents/IWM_Policy.pdf]. Site accessed on 24th March 2010

Coetzee, B., 2009.' Consultant's Briefing: Solid Waste Management Municipal Systems Act S.78(3)RFP 554C/2008/09' prepared by the Solid Waste Management Department of the City of Cape Town. Available online at: [http://www.capetown.gov.za/en/solidwaste/Documents/SWMT%20S78%283%29%20consultants%20briefing%209%20June%202009.pdf]. Site accessed29th March 2009

Cohen, S., 2005. 'Solid Waste Management Alternatives for The City of New York' prepared for New York City Economic Development Corporation, The Earth Institute at Colombia University. Available online at: [http://www.columbia.edu/cu/mpaenvironment]. Site accessed 17th June 2010

Cooper, C. David., 1992. 'Landfill Gas Emissions' prepared by the State University System of Florida for Florida Centre for Solid and Hazardous Waste Management, Report #92-2. Available online at: [http://www.energyjustice.net/lfg/factsheet-lfg.pdf]. Site accessed 16th March 2010

Daskalopoulos, E., Badr, O., Probert, S. D., 1998. 'An Integrated Approach to Municipal Solid Waste Management' in Resources, Conservation and Recycling 24 (1998) 33–50

DEAT, 2000. 'White Paper on Integrated Pollution and Waste Management for South Africa' prepared by the Department of Environmental Affairs and Tourism, No. 227

DEAT, 2009. 'State of the Environment'. Available online at [http://soer.deat.gov.za/themes.aspx?m=58]. Site accessed 16th March 2010

Department of Energy, 2010. 'IRP Input Parameters'. Available online at: [http://www.doe-irp.co.za/IRPPrm/IRP%20Parameter%20-%20S3%20Discount%20Rate.pdf]. Site accessed 16th August 2010.

Department of Minerals and Enegy. 2008. 'National Response To South Africa's Electricity Shortage'. Available online at: [http://www.info.gov.za/otherdocs/2008/nationalresponse_sa_electricity1.pdf]. Site accessed 25th November 2010

Department of Minerals and Energy, 2003. 'White Paper on Renewable Energy'. Available online at: [http://www.dme.gov.za/pdfs/energy/renewable/white_paper_renewable_energy.pdf]. Site accessed 11th March 2010.

de Wit, M., 2009. 'Costing the Integrated Waste Management Bylaw'. Keynote address at City of Cape Town Waste Minimisation Summit, 17th March 2009

Diaz, L. F., Savage, G. M., Eggerth, L. L., and Golueke, C. G., 1993. ' Composting and Recycling of Municipal Solid Waste. Lewis Publishers, Boca Raton, USA

Eberhard, Anton, 2004. 'The political economy of Power Sector Reform in South Africa'. Working Paper number 6, Program on Energy and Sustainable Development, Stanford.

Eberhard, A A, Thompson, F, Davis, M, Horvei, T., 2001. 'The electricity supply industry: economic and social effects of restructuring'. A Business Map Report. October 2001.

Eisenmann, 2010. Personal Interview. 26th August 2010

Endress and Hauser, 2010. Personal Interview. 26th August 2010
Environmental Protection Agency, 2008. 'Dioxins and Furans'. Available online at: [http://www.epa.gov/waste/hazard/wastemin/minimize/factshts/dioxfura.pdf]. Site accessed 18th March 2010.

Environmental Protection Agency, 2002. 'What is Integrated Solid Waste Management?' Available online at [http://www.epa.gov/globalwarming]. Site accessed 24th March 2010

Environmental Protection Agency, 2010. 'GreenHouse Gas Emissions'. Available online at: [http://www.epa.gov/osw/hazard/wastemin/minimize/factshts/dioxfura.pdf]. Site accessed 30th June 2010.

Environmental Protection Agency, 2010. 'Electricity From Municipal Solid Waste'. Available online at: [http://www.epa.gov/cleanenergy/energy-and-you/affect/municipal-sw.html]. Site accessed 27th August 2010.

Eskom Annual Report, 2009. Available online at: [http://www.eskom.co.za/annreport09/ar_2009/profile_key_facts.htm]. Site accessed 9th March 2010.

Eskom, 2007. 'Building a Powerline'. Available online at: [www.eskom.co.za/content/ES%200004ElectrCostBenefRev4.doc]. Site accessed 10th December 2010

Eskom, 2009. ' Ankerlig and Gourika Gas Turbine Power Stations' produced by Generation Communication, GS 0003 Revision 1. Available online at: [http://www.eskom.co.za/content/GS_0003AnkerlGouriTechBrochRev1~1.pdf]. Site accessed 25th November 2010

Eskom, 2010. Tariffs and Charges – 2010/11. Available online at: [http://www.eskom.co.za/content/Tariff%20Book%202010_11~1.pdf]. Site accessed 13th December 2010

Estevez Weinstein, P., 2006. 'Waste-to-Energy as a Key Component of Integrated Solid Waste Management for Santiago, Chile: A Cost-Benefit Analysis'. Department of Earth and Environmental Engineering, Columbia University.

European Energy Agency, 2010. 'Municipal waste generation (CSI 016) - Assessment published Nov 2010'. Available online at: http://www.eea.europa.eu/data-and-maps/indicators/municipal-waste-generation/municipal-waste-generation-assessment-published-3. Site accessed 31st October 2011

European Union Knowledge Network, 2007. 'BioGas CHP: Tilburg, The Netherlands'. Available online at: [http://www.eukn.org/binaries/eukn/netherlands/practice/2007/10/biogas-chp--tilburg---netherlands.pdf]. Site accessed 12th March 2010.

Evans G, 2001. 'Biowaste and Biological waste treatment' Published by James & James, London

eWaste Association of South Africa, 2010. Available online at: [http://www.e-waste.org.za/]. Site accessed 29th March 2010

Faaij, A., Van Ree, R., Waldheim, L., Olsson, E., Oudhuis, A., van Wijk, A., Daey-Ouwens, C., & Furkenburg, W., 1997. ' Gasification of Biomass Waste and Residues for Electricity Production' in Biomass and Bioenergy Vol. 12, No. 6, pp. 387-407, Published by Elsevier Science Ltd

FOE, 2009. 'Pyrolysis, Gasification and Plasma'. Available online at: [http://www.foe.co.uk/resource/briefings/gasification_pyrolysis.pdf]. Site accessed 21st April 2010.

GAIA, 2006. 'Incineration in Disguise'. Available online at [http://www.no-burn.org/article.php?id=283]. Site accessed 18th August 2010.

Gets, A., 2010. Personal Interview. 20th July 2010

Gomez, E., Amutha Rani, D., Cheeseman, C. R., Deegan, D., Wise, M., Boccaccini, A.R., 2009. 'Thermal plasma technology for the treatment of wastes: A critical review' in Journal of Hazardous Materials

Government Gazette, 2009. 'National Environmental Management: Waste Act 2008'. Available online at: [http://www.info.gov.za/view/DownloadFileAction?id=97351]. Site accessed 23rd April 2010

GreenPeace, 2010. Available online at: [http://www.greenpeace.org/international/campaigns/toxics/incineration/the-problem]. Site accessed 18th March 2010.

Haasbrook, A., 2010. Personal Interview. 13 August 2010.

Haider, S., 2010. Personal Interview. 10th February 2010.

Hartmann, H & Ahring Birgitte K., 2005. 'Anaerobic digestion of the organic fraction of municipal solid' in Water Research 39

Hirschhorn, Jackson and Baas, 1993. 'Towards Prevention – the emerging environmental management paradigm', in Clean Production Strategies – Developing Preventative Environmental Management in the Industrial Economy.

Heeb, F., 2009. 'Decentralised anaerobic digestion of market waste, Case study in Thiruvananthapuram, India' prepared for the Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland. Available online at: [http://www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_swm/downloads_swm/ad_market_waste.pdf]. Site accessed 21st June 2010.

Heimlich, J.E., Hughes, K. L., and Christy, A. D., 2005. 'Integrated Solid Waste Management' prepared by the Ohio State University Extension. Available online at: [http://ohioline.osu.edu]. Site accessed 24th March 2010

IPPTS, 2010.' Anaerobic Digestion'. Available online at: [http://www.waste-technology.co.uk/AD/ad.html]. Site accessed 23rd April 2010.

Intergovernmental Panel on Climate Change, 2001. 'Climate Change 2001: Mitigation, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change' prepared by B. Metz, O. Davidson, R. Swart and J. Pan (Eds.). Cambridge University Press, UK.

International Energy Agency technology review, 1997. Available online at: [http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1166]. Site accessed 2nd March 2010

Kavouras, P., Kaimakamis, G., Ioannidis, Th., Kehagias, Th., Komninou, Ph., Kokkou, S., Pavlidou, E., Antonopoulos, I., Sofoniou, M., Zouboulis, A., Hadjiantoniou, C., Nouet, G., Prakouras, A., Karakostas, Th., 2003. 'Vitrification of lead-rich solid ashes from incineration of hazardous industrial wastes' Waste Management 23 (2003) 361–371.

KAB, 2006. 'Source Reduction and Reuse'. Available online at: [http://www.kab.org/site/PageServer?pagename=source_reduc_reuse#NRC]. Site accessed 25th November 2010.

Kiser, V., 2003. 'Recycling and Waste-to-Energy: The Ongoing Compatibility Success Story'. Available online at: [http://www.mswmanagement.com/may-june-2003/recycling-and-waste.aspx]. Site accessed 18th March 2010.

Kiser, J. V. L., & Burton B. K., 1992. 'Energy from Municipal Waste: Picking up where Recycling leaves Off' in Waste Age Magazine, November 1992

Klaas, Donald, L., 1998. 'Chapter 12: Microbial Conversion – Gasification' in Biomass for Renewable Energy, Fuels and Chemicals. Academic Press Limited, California, USA

Klein, A., 2002. 'Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes' prepared by the Department of Earth and Environmental Engineering, Fu Foundation School of Engineering and Applied Science, Columbia University

Knox, A., 2005. 'An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)' prepared by University of Western Ontario for the ONEIA Energy Subcommittee

Kumar, S., 2000. 'Technology options for municipal solid waste-to-energy project'. Maharashtra Energy Development Agency. TERI Information Monitor on Environmental Science 5(1)

Leavens, K., 2003. 'Refuse Derived Fuel, Current Practise and Perspective – Final Report' prepared for the European Commision. Available online at: [http://ec.europa.eu/environment/waste/studies/pdf/rdf.pdf]. Site accessed 30th August 2010

Raje, J., 2007. 'The Clean-tech Report' prepared for Lux Research. Available online at: [http://www.luxresearchinc.com/pdf/08CTR_tech_profile.pdf]. Site accessed 23rd April 2010

Mata-Alvarez , J. Mace, S. Llabres, P., 2000. 'Anaerobic digestion of organic solid wastes: An overview of research achievements and perspectives' Review Paper, Bioresource Technology 74,

Michaels, T., 2009. 'Renewable Energy From Waste' in Energy Recovery Council. Available online at: [http://wte.org/userfiles/file/090421%20Waxman%20ltr%20re%20ACESA.pdf]. Site accessed 20th April 2010.

Monnet, F., 2003. 'An Introduction to Anaerobic Digestion of Organic Waste' prepared for Zero Waste Scotland. Available online at: [http://www.biogasmax.eu/media/introanaerobicdigestion__073323000_1011_24042007.pdf]. Site accessed 20th April 2010.

Morris, M., & Waldheim, L., 2000. 'Energy recovery from solid waste fuels using advanced gasification technology' in Waste Management Volume 18, Issues 6 – 8

Mullen, J. F., Dangtran, K., Mayrose, D., 2000. 'A Comparison of Fluid Bed and Multiple Hearth Biosolids Incineration' Paper Presented At The 14th Annual Residuals & Sludge Management Conference, February 27- March 1, 2000.

Murphy, J & McKeogh, E., 2004. 'Technical, economic and environmental analysis of energy production from municipal solid waste' Renewable Energy 29 2004

Nemerow, N. L., Agardy, F., J., Sullivan, P., & Salvato, J., A., 2009. 'Environmental Engineering, Sisth Edition: Environmental Health and Safety for Municipal Infrastructure, Land Use and Planning, and Industry'. Published by John Wiley & Sons, Inc., Hoboken, New Jersey

NERSA, 2008. 'Inquiry into the National Electricity Supply Shortage and Load Shedding'. Available online at: [http://www.agbiz.co.za/Portals/0/Agbiz%20intel%20Electricity/NERSA%20Report%20-%20Electricity%20supply%20and%20load%20shedding.pdf]. Site accessed 22nd March 2010.

NERSA, 2009. 'Media Statement: NERSA decision on REFIT'. Available online at: [http://www.nersa.org.za/documents/Press%20Release/Media%20Statement%20Announcement%20of%20REFIT%20decision%2031%20March%202009.pdf]. Site accessed 11th March 2010

NERSA, 2009. 'Renewable Energy Feed in Tariffs – Phase II'. Available online at: [http://www.nersa.org.za/Admin/Document/Editor/file/Electricity/Legislation/Regulatory%20Rules/RULES%20FOR%20SELECTION%20CRITERIA%2019%20Feb10.pdf]. Site accessed 15th June 2010

Newton, R., 2005. 'The Project Manager: Mastering the art of delivery'. Published by Pearson Education Limited, Great Britain

Njobeni, S., 2010. 'Eskom's profit soars on higher tariffs'. Available online at: [http://www.businessday.co.za/articles/Content.aspx?id=127666]. Site accessed 25th November 2010

Palacios, J., Alonso, G., Ramírez, R., Gómez, A., Ortiz, J., Longoria, L., 2010. 'Levelized costs for nuclear, gas and coal for Electricity under the Mexican scenario' prepared for the Instituto Nacional de Investigaciones Nucleares, Mexcio. Available online at: [http://www.osti.gov/bridge/purl.cover.jsp;jsessionid=0601934AA71D50B6D2AAE4C29616B120?purl=/840500-YJxBpR/native/]. Site accessed 9th June 2010.

PET Recycling Company, 2010. Available online at: [http://www.petco.co.za/ag3nt/system/about_petco_01_glance.php]. Site accessed 29th March 2010

Peters, S., Timmerhaus, K. D., West, R. E., 2003. 'Plant Design and Economics for Chemical Engineers' Fifth Edition, McGraw-Hill Higher Education, New York, NY 10020, 2003.

Pollack, M., 2009. 'Integrated Waste Management by-law'. Available online at: [http://www.capetown.gov.za/en/Pages/IntegratedWasteManagementby-law.aspx]. Site accessed 31st March 2010

Purser, F. 2010. Personal Interview. 20th July 2010

Rambøll Consulting, 2006. 'The most efficient waste management system in Europe - Waste-to-energy in Denmark' prepared for Renosam Publishers.

Renkow, M., Rubin, A., 1998. ' Does municipal solid waste composting make sense?' in Journal of Environmental Management (1998) **53**, 339–347, Article No. ev980214

Rovaglio, M., Manca, D., Biardi, G., 1998. 'Dynamic modeling of waste incineration plants with rotary kilns: Comparisons between experimental and simulation data' in Chemical Engineering Science, Vol. 53, No. 15, pp. 2727-2742, Elsevier Science Ltd.

SAWIC, 2009. Available online at: [http://www.sawic.org.za/?menu=13]. Site accessed 23rd April 2010

Schilli, J. W., 2004. 'Using Gasification to Process Municipal Solid Waste' A Publication of the Environmental and Resource Management Group of HDR, Volume 12, No. 4 Winter 2004

South Africa.info, 2009. Available online at: [http://www.southafrica.info/business/economy/econoverview.htm]. Site accessed 16th March 2010.

Sustainable Energy Africe, 2009. *Chapter 8: Waste to Energy* in 'City Energy Implementation Manual'. Available online at: http://www.cityenergy.org.za/implementation/waste-energy. Site accessed 31st October 2011

Stengler, E., 2005. 'The European position – Where is waste-to-energy, and where is it going?' in Waste Management World, Nov/Dec 2005.
Stern, D. I. 2003. 'Energy and Economic Growth'. Department of Economics, Sage 3208, Rensselaer Polytechnic Institute, 110 8th Street Troy.

TodaySure, 2010. Personal Interview. 27th July 2010

Carlesi, L. M., 2001. 'Brescia Waste Incinerator' prepared for Arte Media Scienza, Milan. Available online at: [http://www.centrovolta.it/laviadellenergia/inglese/produzione/brescia.htm]. Site accessed 12th March 2010

The Glass Recycling Company, 2010. Available online at: [http://www.theglassrecyclingcompany.co.za/]. Site accessed 29th March 2010.

Themelis, N., 2003. 'An overview of the global waste-to-energy industry' in Waste Management World, Review Issue, July-August 2003

Themelis, N. and Millrath, K., 2004. 'The Case for WTE as a Renewable Source of Energy' prepared for the 12th North American Waste-to-Energy Conference. Savannah, GA. May 2004.

Tsekoa, T., Hui, C., Jayiya, T., Johannessen, N., Hara, M., 2007. 'Waste Characterisation Surveys in the City of Cape Town: Second Draft' prepared for the Department of Environmental Affairs and Development Planning, submitted 17th April 2007

Turton, R., Bailie, R. C., Whiting, W. B., Shaeiwitz, J. A., 2003. 'Analysis, Synthesis, and Design of Chemical Processes – Second Edition' Pearson Education, Inc. Upper Saddle River, New Jersey, 2003

UNFCCC, 2010. 'Letter including Nationally Appropriate Mitigation Actions'. Available online at: [http://unfccc.int/files/meetings/application/pdf/southafricacphaccord_app2.pdf]. Site accessed 18th August 2010.

Verma, S., 2002. 'Anaerobic Digestion of Biodegradable Organics in Municipal Solid Wastes' prepared by the Department of Earth & Environmental Engineering for the Fu Foundation School of Engineering & Applied Science, Columbia University, 2002

Van Vuuren, A. 2010. Personal Interview. 27th July 2010

Vik, Thomas E., 2003. 'Anaerobic Digester Methane to Energy: A Statewide Assessment' prepared for Focus on Energy, 2003

Williams, P., T., 2005. ‘ Waste Treatment and Disposal: Second Edition’. John Wiley & Sons Ltd, The Atrium, England.

Winkler, H (ed)., 2007. ‘Long Term Mitigation Scenarios: Technical Report’ prepared by the Energy Research Centre for Department of Environment Affairs and Tourism, Pretoria, October 2007

Yassin, L., Lettieri, P., Simons, S. J. R., Germana, A., 2009. ‘Techno-economic performance of energy-from-waste fluidized bed combustion’ in Chemical Engineering Journal 146, 2009

Appendixes

Appendix A: MSW Collection in Cape Town

- Residential: MSW collection is carried out for single title properties, group housing schemes and sectional titles in residential areas. For single title residential properties and group housing schemes each residence is issued with one 240litre container. This is collected once a week during weekdays according to a pre specified schedule. For sectional title properties, the relevant body corporate is issued with the required number of containers. These are also collected once a week during weekdays according to a pre specified schedule. It is the responsibility of the home owners association to ensure than containers are placed on pavements in suitable areas. Garden waste collection is not offered as a service by the municipality but residents can apply for ad-hoc garden refuse collection at an additional cost (CoCT, 2010).

- Non-Residential: Non-residential entities that are seen as industrial or commercial (businesses, schools or government departments) may use the City's collection services or a service provider of their choice. If non-residential customers opt to use the City's service then they must sign a service agreement and specify how many containers they require and how often collection is needed, be it three or five times a week. If private companies carry out the required service, property owners need to complete a waste assessment form (CoCT, 2010).

- Special Events: The City does offer services to registered business partners of Non-Profit Organisations (NPOs) that include management of waste during events such as festivals. This is subject to availability of resources, may not exceed 21 calendar days and may not exceed one hundred and fifty 240 litre containers per event (CoCT, 2010).

- Special Waste: The City does not have the required facilities and infrastructure in place to deal with the handling, transport and treatment of special waste including hazardous, dangerous and medical waste. Private waste collectors therefore offer these services (CoCT, 2010).

- Area Cleaning: The City of Cape Town's Solid Waste Management Department is responsible for ensuring general cleanliness in streets and public spaces within its jurisdiction. Scheduled cleaning programmes are set and are responsible for the picking up of litter. New litter bins have been designed and are being placed in areas such as business areas, transport interchanges and places where there is a large amount of pedestrian traffic. Street cleaning is carried out according to street cleaning programmes and happens from one property boundary to the opposite property boundary. It consists of litter picking and cleaning of the sidewalks and street (CoCT, 2010).

- Illegal Dumping: Illegal dumping is one of the biggest problems that the City of Cape Town encounters and it spends millions of Rands a year cleaning it up. Examples of illegal dumping include garden waste, recyclables, residential waste and builders' rubble. This often occurs on public or private property. The City has introduced strict laws to punish offenders and a recently created Solid Waste By-Law Enforcement team has been put in place to ensure that all by-laws are strictly enforced (CoCT, 2010).

- Informal Settlements: Community based contracts are responsible for the cleaning and collection of domestic refuse in informal settlements. Each dwelling is provided with sufficient black bags and when full are collected on a weekly door-by-door basis. They are then taken to a container at a centralised collection point. It is then transported to a landfill site for disposal (CoCT, 2010).

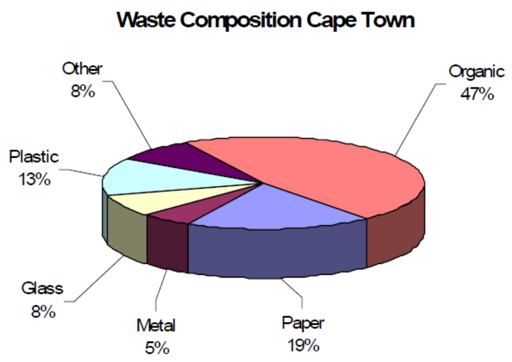
Appendix B: Waste Generation in Cape Town

Types of Waste Generated in Cape Town

The waste that is generated in Cape Town can be broken down into two main categories with sub-categories within each (CoCT, 2006).

1. Residential Waste: This waste category can be broken down into residential waste, special or bulky residential waste and garden waste. Each of these is classed as general, non-hazardous waste and includes recyclable and non-recyclable waste, vegetation and vegetable matter that biodegradable. Garden waste is dealt with at special facilities provided by the council at pre-selected sites. A total of 1684 tons of residential waste is generated daily.
2. Non-Residential Waste: This waste category covers a wide range of waste classes including builder's waste, commercial and retail waste, industrial waste, special industrial hazardous waste, special industrial dangerous waste, health services waste and nuclear or radioactive waste.
    - Builder's waste can either be non-hazardous or contaminated and both are not for general landfill. Instead special facilities are provided by the Council at pre-selected sites.
    - Commercial and retail waste is a non-hazardous type of waste and includes recyclable and non-recyclable wastes for normal collection and those too large for normal collection
    - Industrial waste has three different classes being general non-hazardous waste, special industrial hazardous waste and special industrial dangerous waste. The general industrial waste includes recyclable and non recyclable wastes for normal collection and/or too large for normal collection. Special industrial hazardous waste includes solid and liquid wastes that are hazardous to human health and the environment and therefore require special arrangements in terms of applicable legislation governing hazardous chemical substances. This class of waste also includes components containing hazardous elements (e.g. electronic circuitry and components, fluorescent tubes, etc). Finally special industrial dangerous waste includes all gasses, solids and substances not covered in the hazardous section. It also includes the residue, by-products or waste relating to the Explosives or Armaments Industries.
    - Health services wastes are a hazardous type of waste and include "sharps", pharmaceutical, laboratory and human wastes including fluids. This also includes veterinary wastes and usually requires special processing and/or destruction through incineration to prevent human health effects and environmental contamination
    - Nuclear or radioactive waste is deemed extremely hazardous and includes wastes or scrap that have been contaminated by nuclear energy sources used in a variety of industries that require special handling, disposal permits, arrangements and nuclear power generation.

Figure 9: Waste Composition of City of Cape Town
Source: AGAMA, 2006



Current MSW Generation in Cape Town

A survey carried in 2007 established that in total the city's landfill sites receive on average 5895 tons of waste daily and 2 151 411 tons of waste annually, with an overall increase of 1414 tons per month. This equates to just under 2kgs per person per year with an annual projected growth rate of 7%. It must be noted that there is a large amount of variability when it comes to data collection of waste figures. The numbers can have a drop or increase from day to day and week to week depending on who collects the data and even the conditions found at various disposal sites around the City. It is therefore important not to get too carried away with the overall tons of waste found in the City but to rather consider a lower and higher value of waste found in the City (Tsekoa et al, 2007).

Table 46: Waste generation records for the City of Cape
Source: Tsekoa et al, 2007

	Daily	weekly	monthly	annually	increasing rate (tons per month)
Tons	3244	22768	98660	1183919	720
free tons	2440	17125	74209	890510	474
Special	211	1481	6418	77012	220
Total	5895	41374	179287	2151441	1414

Appendix C: Characteristics of MSW

Typical Composition of MSW in Cape Town

The MSW collected in Cape Town consists of a range of materials including paper and cardboard, glass, plastics, organic waste, wood waste, metals, builder's rubble, E-waste, textiles, industrial waste, household waste and medical waste. A breakdown of general waste found in Cape Town can be seen in Figure 10 and are as follows: Recyclable glass (bottles & jars) is the highest at 14%, followed by organic waste at 11%. Brown K4 cardboard, mixed paper and textiles-clothing each contribute 7%. Office paper (6%), food waste (5%), light steel (4%) glossy magazines (4%) PET plastics (4%) and LDPE plastics (4%) are also significant. Therefore 59% of Cape Town's general waste has the potential to be either recycled or is readily bio-degradable (Tsekoa et al, 2007).

Figure 10: Waste category of City of Cape Town based on 2007 projections
Source: Tsekoa et al, 2007

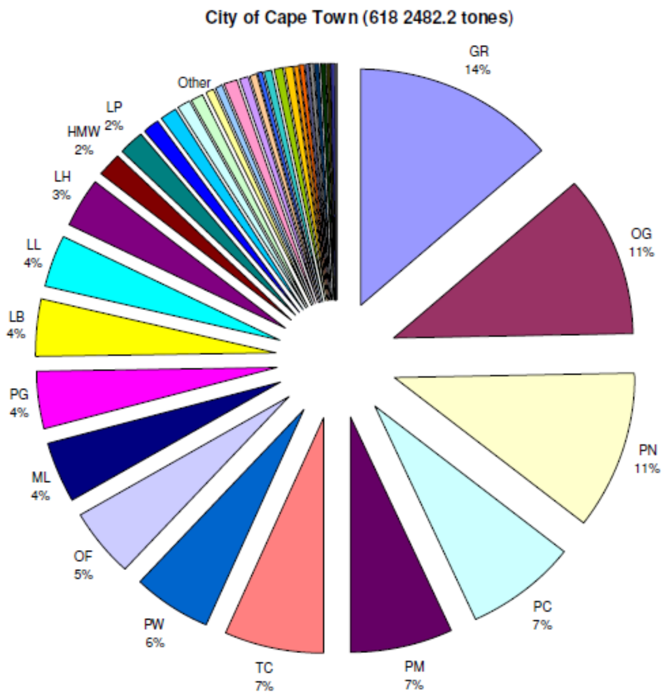


Table 47: Legend for figure 12

Symbol	Description
GR	Recyclable glass
OG	Green organic waste
PN	Newspaper
PC	Cardboard (Brown K4)
PM	Mixed Paper
TC	Clothing, fabric, shows, carpets
PW	White & coloured office paper
OF	Food waste (putrescible)
ML	Light steel (beverage and food cans)
PG	Glossy magazines
LB	PET (plastic beverage bottles)
LL	LDPE (plastic bags & other soft plastics)
LH	HDPE (milk bottles, 20l containers etc.)
HMW	Household medical waste (nappies, tablets, etc.)
LP	Polystyrene

Recyclable Component

Figure 11 shows the major recyclable materials for the City of Cape Town. The results for the recyclable material reveal the following: Paper will be the most available recyclable category at 39% followed by Organic material at 17% of the total (Tsekoa et al, 2007).

Figure 11: Projected (2007) annual recyclables for the City of Cape Town
Source: Tsekoa et al, 2007

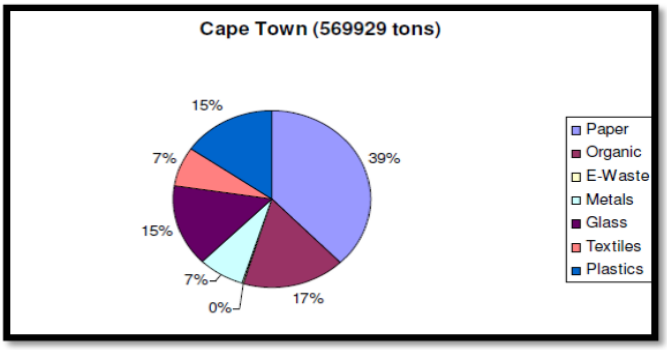
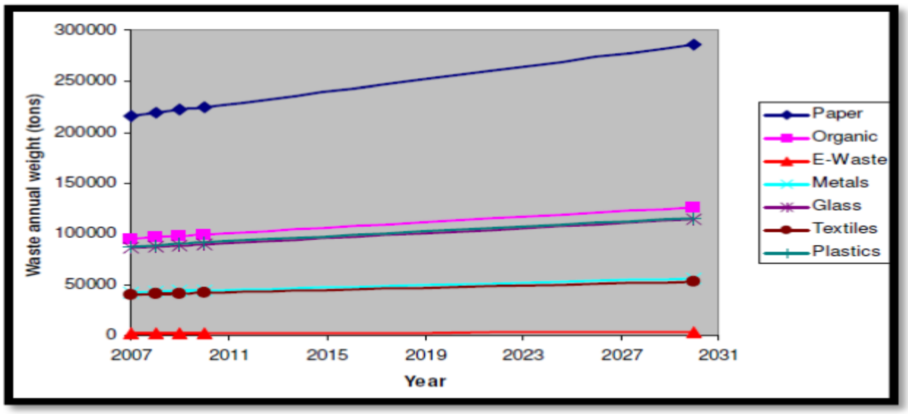


Figure 12 provides an illustration of projected annual weights of the major recyclable material originating from all the sectors. The figure shows that there will more than likely be a constant growth in the amount of the recyclables for the City. Paper will dominate the amount in weight of recyclable material, while E-Waste continues to not feature prominently. Metals also don't feature, but this is probably because they tend to not form part of the Municipal collection system (Tsekoa et al, 2007).

Figure 12: Annual waste projected for major recyclable waste from 2007 to 2030 for the City of Cape Town
Source: Tsekoa et al, 2007



Appendix D: Waste Disposal

Currently, the City of Cape Town has six landfill sites. Only three of these are in operation and will reach their capacity within the next five to 13 years. Degradation at a landfill site depends on the type of waste, moisture content within the landfill and other variables. Organic waste generally degrades quicker than inorganic materials. Table 12 provides a summation of the remaining landfill air space and lifespan of the three remaining operational sites at Coastal Perk, Visserhoek and Bellville South (CoCT, 2010).

Table 48: Remaining landfill air space and lifespan 2007
Source: De Wit, 2009

Landfill	Remaining Footprint (Ha)	Remaining Airspace (m^3 x million)	Remaining Airspace (tonnes x million)	Current Deposition Rate (T/month)	Remaining Site Life (Years)
1. **Coastal Park**	20	7.0	5.7	**40,000**	**9**
2. **Bellville South**	18 (10 lined)	6.0	4.8	**70,000**	**5**
3. **Vissershok**					
3(a) Vissershok South	28 (8 lined)	9.0	11.3	**100,000**	**6**
3(b) Additional 10m height	70	6.0	7.5	**-**	**4**
3(c) The Triangle	12	4.0	5.0	**-**	**3**
3(d) Vissershok North	50	16.0	20.0	**-**	**9**
4. **New Site**	176	68.8	55.0	**-**	**30**
Total	374	116.8	109.3	**210,000**	

Currently new locations are being assessed for a new site to cope with the city's growth. Swartklip, Brackenfell and Faure no longer accept waste as they are all full. Consequently two new sites are being considered. The first is south of Atlantis within the Koeberg exclusion zone, the second is at KalbasKraal near Philidelphia, also up the West Coast. The City estimates that the final expenditure will be between R1.2 and R2 billion. One must bear in mind that these sites are not within close proximity to Cape Town and therefore additional costs of transport will make these sites even more prohibitive (CoCT, 2010).

Salvaging at operational landfills occurs regularly as this helps make more efficient use of available airspace. Contractors are employed to salvage material from the landfill, although this will be discontinued at Visserhok as it is the only hazardous facility in the country that still allows salvaging. A material recycling facility has also been developed at the transfer station at Athlone, where waste is sorted and streamed.

Transfer Stations

Transfer stations play an important role in waste disposal in Cape Town. When there are cases where distances for internal and external refuse collection service providers are too far to travel, transfer stations can be used to dispose of the waste. The waste at these stations is then compacted into 20 ton loads and transferred via rail to landfill sites. The city currently has two transfer sites at Athlone and Swartklip respectively from which fifty 20 ton containers of compacted waste are transported via rail to the Visserhoek landfill site. This system currently works very well to the current disposal sites, however logistically it may begin to prove challenging to the new disposal sites outside of Cape Town (CoCT, 2010).

Appendix E: Recycling in Cape Town

Recycling is not part of the City of Cape Town's Constitutional mandate. The City feels that recycling rather requires various industries to develop and drive this process. "The Council will, however, encourage and support development initiatives that will enable and encourage economic and job-creation opportunities linked to the establishment of processing and recycling businesses in the City as part of the socio- economic development objectives for the City of Cape Town (Tsekoa et al, 2007: 31)". The support from the City is limited to initiatives that are environmentally and economically sustainable by the owners of any recycling businesses.

The City is however constantly promoting recycling through its website and has introduced two initiatives over the past five years to help encourage recycling in Cape Town: IWEX and Think Twice

1. IWEX: The Integrated Waste Exchange (IWEX) is a free online system that enables waste generators and users to exchange waste materials. IWEX facilitates the re-use of waste, subsequently conserving energy, decreasing resource use and finally decreasing the pressure on Cape Town's already pressurised landfill space. The service has been made available free on the City of Cape Town's website to anyone who generates or uses waste. This includes private companies, institutions, schools and individuals (CoCT, 2010).

   The benefits of IWEX include turning the fixed costs of waste storage, transport and disposal into savings; providing companies with a competitive edge in the sustainable usage of resources; and finally IWEX can help businesses locate alternative material suppliers at competitive prices, thereby lowering raw material and input costs (CoCT, 2010)

2. Think Twice: This initiative has been introduced to extend the life of the City's landfill sites. It was launched in November 2007 and has so far diverted 534 057kg of waste away from landfill. Waste Plan collects recyclables bag found in residential bins from the City and takes them to a materials recovery facility in Maitland for reprocessing. By using Think Twice, carbon emissions decrease as those used to make new resources from these materials ceases. It will also boost employment within the recycling industry (CoCT, 2010)

It must also be noted that there is a considerable monetary value attached to recycling in Cape Town. Table 51 shows that there is positive potential for recycling small enterprises operated and managed by individuals and subsequently the income generation from recyclable waste in rather large. Of all the materials, plastic is expected to the highest value at R78, 882, 000, which accounts for roughly 36% of recyclable materials seen in the table.

The table also highlights the importance of plastic, paper and cardboard recycling initiatives for helping the poor and increasing employment. This is due to the ease of availability and movement of these products. It must also be noted that recycling initiatives should be directed at the source level as a means of reducing waste ending up at the landfill.

Table 49: Projected annual monetary values of the major categories of recyclable waste for the years 2007 to 2030
Source: Tsekoa et al, 2007: 93

Recyclables	2007	2008	2009	2010	2030
Paper & Cardboard	R 51,452,790	R 52,175,630	R 52,898,980	R 53,622,000	R 68,082,130
Glass	R 22,481,280	R 22,797,180	R 23,113,350	R 23,429,250	R 29,747,250
Plastics	R 78,882,000	R 79,990,800	R 81,100,800	R 82,207,200	R 104,376,000
Organic	R -	R 0	R 0	R 0	R 0
Metals	R 63,776,380	R 64,666,900	R 65,569,480	R 66,460,000	R 84,391,320
Textiles	R -	R 0	R 0	R 0	R 0
*Tyres	R -	R 0	R 0	R 0	R 0
E-Waste	R 1,089,450	R 1,105,200	R 1,120,050	R 1,135,800	R 1,441,800
Annual Totals	R 217,681,900	R 220,735,710	R 223,802,660	R 226,854,250	R 288,038,500

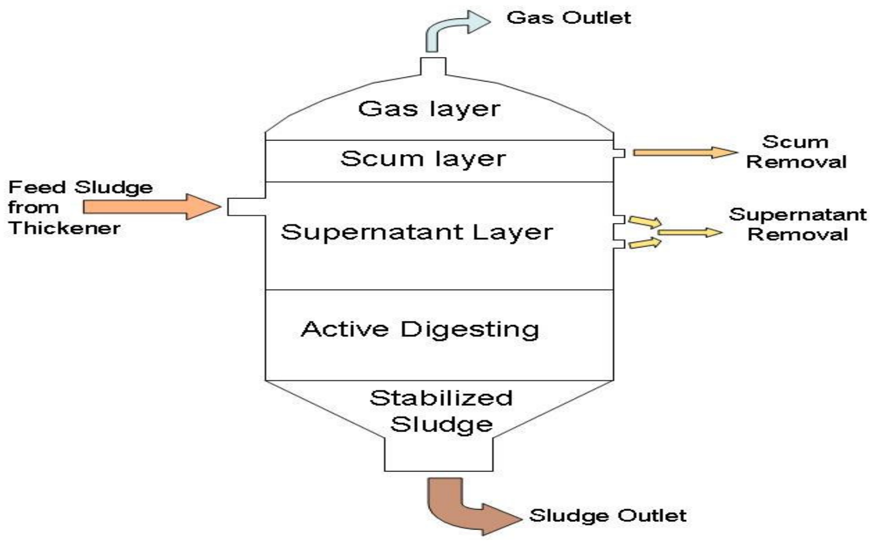
* Projections assumed the 2007 price for all material

Appendix F: Five Types of Anaerobic Digestion Processes

There are five main types of anaerobic digestion processes that can be considered and are dependent on the characteristics of the organic waste that is processed by AD (Hartmann & Ahring, 2004):

1. Wet continuous digestion: The waste that is used in the digester is mixed with a large proportion of water giving a feedstock of 10% dry solids. The type of digestion is ideal for co-digestion of biodegradable waste with sewage sludge

Figure 13: Typical anaerobic sludge digesting (continuous) at a wastewater works (AGAMA, 2009)



2. Multi-stage wet digestion: This occurs when municipal solid waste if added to recycled liquor resulting in a fermentation of the mixture by micro-organisms that then release volatile fatty acids. These acids are then put through a high rate industrial digester and converted into gas.
3. Dry batch digestion: Waste is fed into the reactor with digested material from another reactor and then the digester is sealed. Leachate is then collected from the bottom of the digester and is circulated to distribute micro organisms and thereby maintain steady moisture levels.
4. Leach-bed process: This process is similar to dry-batch digestion. The difference occurs after the third stage of methanogensis. Once this is reached the reactor is connected to a fresh batch of waste in a second reactor.
5. Dry continuous digestion: In this type of digestion waste is fed continuously into a digestion reactor with 20 – 40% dry matter).

Appendix G: General assumptions for incineration, gasification and centralised AD financial models

Parameter	Level	Reason for choice
Electricity Price (Incineration and gasification)	R182.32 per MWh of electricity generated.	This price represents the price that Eskom would pay the municipality for the generated electricity. This has been inflated from R150 per MWh in 2006. This price is inflated in year 1, 2 and 3 by 25%, in line with current NERSA approved tariff increases. From year 4 the price is inflated at a 5% annual inflation rate (AGAMA, 2006).
Electricity Price (Centralised AD)	The electricity price is R960/MWh of electricity generated.	This price is based on the REFIT released by NERSA in 2009. This gave provisions for certain renewable energy technologies, including biogas of which anaerobic digestion is included (NERSA, 2009: 15). This price is only applicable to centralised AD and not decentralised AD as there is no provision given for facilities of less than 1MW generation
Selling price of Commercial Compost	R1000 per tonne of compost.	This assumption is only applicable to the centralised AD model. It is based on an average high price paid for commercial pelletized compost and regular garden compost in the metropolitan area of Cape Town (Haasbrook, personal interview, 2010). This price is inflated by 5% from year 1
Avoided costs associated with landfill airspace savings	R303.88 per tonne of airspace saved by not sending waste to landfill.	This price is inflated at the inflation rate of 5% from year 1 (AGAMA, 2006).
Avoided CO_2 Emissions	The value of a ton of avoided CO_2 emissions is R65/ton of avoided CO_2	This price is inflated at the inflation rate of 5% from year 1 (AGAMA, 2006)
Environmental Impact Assessments	To be carried out during year 0 and year 1	For each scenario it has been assumed that there is a two year window necessary to carry out Environmental Impact Assessment
Land purchase and	Land will cost R650 000	For each scenario it has been assumed that

rezoning	per hectare	there is a two year window necessary to carry out land purchase and rezoning (AGAMA, 2006)
Project design, commission and construction	Construction is assumed to cost R500 000 per hectare of construction carried out	To be carried out during year 3 and year 4. The capital costs and construction costs are therefore accounted for in years 3 and 4 (AGAMA, 2006).
Operational Status	Year 5	Each plant will only be operational in the fifth year, at which stage it will begin to generate income.
Depreciation of fixed capital	Straight Line over 10 years	Depreciation will be accounted for from year 6 and will be calculated over a 10 year, straight line basis. Depreciation is subtracted as a cost before income tax charges are calculated and paid, and net profits are reported to stockholders.
Working Capital	5% of fixed capital	Working capital is required in the first year of operations only – Year 5
Discount Rate	8%	There is considerable debate regarding the appropriate discount rates for long-term planning, however a real discount rate of 7-10% is generally used for power sector planning. This study will use a discount rate of 8%, reflecting the rate approved by NERSA for State Owned Enterprised's (DOE, 2010)
Tax Rate	28%	The current rate of tax for companies in South Africa.

Appendix H: General assumptions of decentralised AD financial model

Parameter	Level	Reason for choice
Electricity Prices	In year 0 of this model the electricity price is R0.18 per kWh of electricity generated	This price is inflated in year 1, 2 and 3 by 25%, in line with current NERSA projections. From year 4 the price is inflated at the normal 5% annual inflation rate (AGAMA, 2006).
Avoided costs associated with landfill airspace savings	R303.88 per tonne of airspace saved by not sending waste to landfill	This price is inflated at 5% from year 1.
Avoided CO_2 Emissions	R65/ton of avoided CO_2 emissions	This price is inflated 5% from year 1 (AGAMA, 2006)
Environmental Impact Assessments	To be carried out during year 0	An EIA for this model is not a requirement. This is because the organic input is less than the threshold for an EIA. A basic assessment is required if more than 5tons per day of organic waste is added. This facility only deals with 3tons of organic waste per day.
Land purchase and rezoning	Land will cost R650 000 per hectare	For the decentralised AD scenario it has been assumed that there is only a one year window necessary to carry out land purchase and rezoning (AGAMA, 2006)
Project design, commission and construction	Construction is assumed to cost R500 000 per hectare of construction carried out	To be carried out during year 2. The capital costs and construction costs are therefore accounted for in this year.
Operational Status	Year 3	Because the decentralised AD system is smaller than any of the other WtE facilities, operational status is achieved much sooner.
Depreciation of fixed capital	Straight Line over 10 years	Depreciation will be accounted for in year 4 and will be calculated over a 10 year, straight line basis
Working Capital	5% of fixed capital	Working capital is required in the first year of operations only – Year 3

Appendix I: Incineration Financial Model

Refer to attached CD Rom for Incineration Financial Model

Appendix J: Gasification Financial Model

Refer to attached CD Rom for Gasification Financial Model

Appendix K: Centralised Anaerobic Digestion Financial Model

Refer to attached CD Rom for Centralised Anaerobic Digestion Financial Model

Appendix L: Decentralised Anaerobic Digestion Financial Model

Refer to attached CD Rom for decentralised Anaerobic Digestion Financial Model