Challenges impeding South African Municipalities from Adopting Waste-to-Energy Schemes: An Exploratory Approach

By

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Submitted in partial fulfilment of the requirements for the degree of

Master of Philosophy in Energy and Development Studies

Energy Research Centre

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University of Cape Town

December 2015

Acknowledgements

- My supervisor, Dr Bothwell Batidizirai – the words ‘thank you’ are not sufficient to express my gratitude for your guidance, time and support. You afforded me the opportunity to explore without limitations and nurtured my ideas – *ndinotenda zvikuru*!
- My dear family – Professor Ashley Mutezo, brothers Rangano and Makomborero – you spared your ears and endless days and nights listening to my ideas about the research objectives, worries about mixed methods and approaches to recommendations, I hope this makes you proud, thank you dearly;
- The local municipalities and private sector companies (Yoav Schmulevich from Anaergia Africa and Jan Palm from Jan Plam Consulting Engineers) who participated in the research – without your time and input this research would not have been what it is - is much appreciated;
- Ms Gracia Mungaga and Mr Tawanda Sango and the rest of The GreenCape team – thank you for the wealth of information you shared as well as guidance, it is much appreciated;
- My friends and classmates (Engr. Rachel Ugye-Ama, Sarah Odera, Ayanda Fuma, Entai Kapfukachira, Genevieve Joubert, Angelique Myburgh and Chad Harris) thank you kindly for your words of encouragement and debates which constantly kept me on my toes and for always offering to assist.
- The National Research Fund (NRF), for your financial support through the RSES Scholarship and for providing an opportunity for further research in the renewable energy sphere, particularly waste-to-energy.

To God be the Glory great things He hath done!

Declaration

I know the meaning of plagiarism and declare that all of the work in the document, save for that which is properly acknowledged, is my own.

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Date:

December 2015

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Acronyms

AD	Anaerobic Digestion (Digester)
ARTS	Athlone Refuse Transfer Station
BOT	Build – Operate – Transfer
CALM	Cape Agulhas Local Municipality
CBO	Community Based Organisations
CEF	Central Energy Fund
CH^4	Methane
CHP	Combined Heat and Power
CMD	Clean Development Mechanism
CoCTMM	City of Cape Town Metropolitan Municipality
CPUT	Cape Peninsula University of Technology
CSIR	Council for Scientific and Industrial Research
DLM	Drakenstein Local Municipality
DoE	Department of Energy
DoEA	Department of Environmental Affairs
DST	Decision Support Tool
EIA	Environmental Impact Assessment
ERA	Energy Regulation Act
GHG	Greenhouse Gas
GLM	George Local Municipality
GtE	Gas-to-Energy (Landfill)
IDP	Integrated Development Plan
IEP	Industrial Energy Plan
IPP	Independent Power Producers
IRP	Industrial Resource Plan
IWMP	Integrated Waste Management Plan
KWh	Kilo-Watt Hour
LFGRS	Landfill gas recovery to energy systems
LM	Local Municipality
m^3	Cubic Meter
MBT	Mechanical Biological Treatment

MFMA	Municipal Financial Management Act (2003)
MSA	Municipal Structures Act (2000)
MSA	Municipal Systems Act (1998)
MSW	Municipal Solid Waste
MW	Mega Watts
MYPD	Multi-Year Price Determinant
NEM: WA	National Environmental Management: Waste Act (2008) and Amendment National Environmental Management: Waste Act Amendment (2014)
NERSA	National Energy Regulator of South Africa
NGO	Non-Government Organisations
NWMS	National Waste Management Strategy
NCV	Net Calorific Value
O&M	Operation and Maintenance
p.a	Per annum
p.d	Per day
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PV	Photovoltaic
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
SAWIC	South African Waste Information Centre
SLM	Stellenbosch Local Municipality
t	tonnes
tpa	tonnes per annum
tpd	tonnes per day
UCT	University of Cape Town
UN	United Nations
UWC	University of the Western Cape
WaR	Waste-as-Resource Facilities
WIS	Waste Information System
WM	Waste Management
WtE	Waste-to-Energy
WWTW	Waste Water Treatment Works

Synopsis

As a resource, waste is abundantly available but largely underexploited in South Africa. Through waste to energy transformation, waste offers a variety of benefits that could address socio-economic and environmental challenges such as energy poverty, decreasing landfill space and greenhouse gas (GHG) emissions. As South Africa becomes more urbanised, the urban population will rapidly increase and greater effort will be required to manage waste and provide energy services. Municipalities have the potential to deal with these challenges and realise many benefits by transforming and valorising waste through waste-to-energy (WtE) schemes. The most prevalent WtE technologies include biological (biochemical conversion) and thermal (thermo-chemical) based conversion technologies. Biological technologies mainly employ anaerobic digestion (AD) of waste to produce biogas which can be used directly or upgraded to other secondary energy carriers. Landfill gas recovery is also based on anaerobic breakdown of waste in landfills. Thermal treatment methods that produce heat and electricity include combustion, gasification, and pyrolysis. The most common form of WtE conversion technology is combustion or incineration of solid waste. In the developing world, AD is the most common technology especially for small scale and domestic applications. WtE technologies have been successfully deployed in many developed as well as some developing countries but there are limited initiatives in South Africa due to a number of barriers to the deployment of the technology.

This study explored the barriers to wide scale deployment of WtE technologies in South Africa with a specific focus on adoption challenges faced by local municipalities specifically in the Western Cape Province. Four objectives were identified, namely: (1) investigate existing waste management methods, challenges experienced and current (proposed) interventions; (2) investigate local municipalities' efforts to implementing WtE schemes and the challenges encountered; (3) estimate the amount of energy that can be produced by local municipalities from waste and the extent to which the energy gap could be narrowed and; (4) identify the most appropriate WtE technology that local municipalities could implement.

The research methodology comprised of a mixed methods approach which encompassed both qualitative and quantitative approaches, based on an exploratory design. A sample of five municipalities was identified and participated, from a population of 24 municipalities in the Western Cape Province. The criteria used to select the municipalities include (1) experiences, plans and efforts to adopt WtE (2) socio-demographic trends such as population growth and

urbanisation rates as well as (3) proximity and ease of collecting data physically. Some challenges that were experienced relate to limited availability and accuracy of waste generation data and waste compositions, limited availability of municipal documents (such as feasibility studies and policy documents) and the inability of participants to answer all the relevant questions. The latter was mainly due to the different stages of WtE implementation in the different municipalities.

Through the analysis, it was noted that socio-demographic trends such as population growth and in-migration increased between the 2001 and 2011 period, which also indicated an increase in the waste generated. Although local municipalities were implementing waste initiatives such as recycling and composting, none had physically implemented any WtE schemes. However, the municipalities were exploring the technologies and were at different stages, mainly at the feasibility stage. The challenges deterring municipalities from adopting WtE include:

1. Unsuitable waste feedstock for energy generation and poor data on waste generation and composition for investment decision making,
2. Restrictions on independent power producers (IPPs) of electricity to directly supply power to municipalities as well as timeous wheeling agreements (the monopoly of Eskom)
3. Poor synchronisation of policies (energy and waste policies do not provide a solid platform for establishing WtE industries),
4. Poor integration of WtE into waste management planning,
5. Limited knowledge of technologies by decision makers and lack of political will;
6. Low landfill tariffs,
7. Limited access to capital to invest in technologies and high investment costs depending on the type of technology,
8. Lack of skills to implement technologies,
9. Limited awareness of the technologies and their benefits and opposition from the public for various reasons including emissions of hazardous gases, and
10. Delays in processing environmental and legal applications.

Despite these challenges WtE technologies, the local municipalities who participated in this study indicated that they are still actively considering adopting WtE and currently there are several feasibility studies being undertaken at different stages to explore WtE in future.

However, due to the different socio-economic and demographic profiles, each municipality would need to consider WtE technologies that are appropriate given their context, such as the waste composition and waste volumes. Thus, not all local municipalities can explore electricity generation from waste via incineration as economies of scale render volumes below 500 tonnes per day (tpd) uneconomic. However, smaller municipalities could consider other technologies such as anaerobic digestion which are viable from small scales.

In terms of the contribution of WtE to meeting energy demand in the selected municipalities, the estimated potential electricity generation from existing waste quantities ranged from 3% to 17% of the current electricity demand levels. Cape Town municipality has potential to generate about 1.8 TWh (or about 17% of the city's total electricity demand). For the other selected municipalities, the potential electricity generation from waste is less than 10% of the current electricity supply. If realised, these potential electricity supplies are very substantial and can make a significant contribution in the municipality energy supply. Therefore, implementing WtE schemes in the selected municipalities could contribute to addressing the electricity shortfalls in the province – on condition that the WtE schemes are economically viable. This assumes that all the identified waste can be mobilised and used for energy production – which in practice is an optimistic assumption. Thus, WtE can make significant contribution to both energy supply and also as an alternative method of managing waste and curbing carbon emissions. As small scale embedded generators, WtE facilities can play a significant role in stabilising the local network and firming the power in the municipalities, and thus reduce the need for load shedding. Furthermore, to improve the bankability of WtE schemes, these schemes should be seen part of broader measures in integrated waste management strategies so as to capture the additional waste management benefits.

Given the quantities and type of waste, smaller municipalities cannot typically recover enough energy to address demand on a large scale, neither can they adopt incineration as a preferred technology. It would be efficient economically for the smaller municipalities to adopt AD technologies since this can be implemented on a small scale. Larger municipalities can recover energy on a larger scale using both incineration and AD technologies. In Africa, generally (and South Africa in particular) other technologies such as biomass gasification and pyrolysis are currently not preferred as there is limited experience in implementing them and therefore carry investment risks.

Keywords: waste, energy poverty, local municipalities, waste-to-energy, adoption challenges,

Chapter One: Introduction

“We must continue research into new forms of energy and into more efficient use of existing energy sources” - Mac Thornberry

1.1 Background

Waste management is one of many challenges facing the urban authorities today, due to its impacts on various socio-economic and environmental issues such as human health, sanitation, and climate change. This challenge is more evident in developing countries where the necessary institutional, technical and financial capacity are less advanced compared to those in developed countries (Fobil, et al., 2005). Despite being a challenge, waste is also a largely under-exploited resource which could potentially offer a wide spectrum of benefits. Some of these benefits include a potential energy production in the form of electricity, heat or gas; improved waste management while minimising landfilling; reduced carbon footprint specifically from waste material by avoiding landfill gas emissions; production of compost/organic fertiliser as well as healthier communities and environments. Various types of waste typically available in municipalities include: municipal solid waste such as domestic and industrial waste, road side cuttings, tree trimmings and garden waste, agricultural residues, as well as waste water and sewage sludge (IPCC, 2006). Although waste has conventionally been regarded as “a by-product or end-of-use material that is to be disposed of” (WC - DEA&DP, 2013), this view has changed over the past few years. Gradually waste is being seen as a valuable resource that could contribute towards sustainable development and economic growth in terms of material recovery and recycling, up-cycling, second generation product manufacturing, etc. However, the potential for energy generation from waste remains largely underdeveloped.

Given the pressure on dwindling landfill space and other complex urban infrastructural demands, there is great need to improve existing waste management techniques especially as rapid population growth and urbanisation will compound the existing strain on the waste management infrastructure. At the same time, there is urgent need to address the growing energy demand and meet the supply shortfall which is periodically experienced in South Africa. In African cities phenomena such as migration, sprawling and decentralisation are increasing the pressure on urban infrastructure, making collection and disposal of waste more difficult (van der Merwe, 2014;Ai, 2011). Generally, the poorer communities in urban areas do not have adequate service delivery and lack of access to water, sanitation and energy. South Africa’s current energy crisis further exacerbates the situation. Generating sufficient energy “to meet the demands of the ever-increasing urban population and growing industrial concerns remains the single major development" challenge in many developing countries (Fobil, et al., 2005). An intervention that has potential to address both waste and energy related challenges, is the generation of energy from waste. Various technologies are available to convert waste into energy – the key categories being biological conversion and thermo-chemical conversion. Thermal conversion of waste to produce electricity and heat include waste incineration, gasification and pyrolysis. Biological treatment is primarily via anaerobic digestion of waste with the production of biogas. Landfill-gas-recovery-to-energy systems (LFGRS) entail CH_4 gas recovery from landfills for electricity and heat generation. Various forms of energy derivable from waste are shown in **Figure 1**:

Figure 1: Energy By-products of WtE Treatments

Biological Conversion

- Bio-diesel
- Electricity
- Heat
- Hydrogen
- Methanol

Thermal Conversion

- Bio-gas
- Bio-ethanol
- Elecctricity
- Hydrogen

Adopted from: World Energy Council (2013, p. 7b.6)

Municipalities are well positioned to drive such waste to energy interventions that can contribute to socio-economic and environmental benefits in their jurisdictions. With that in mind, this study aims to expose the challenges impeding South African local municipalities from adopting waste-to-energy (WtE) schemes.

1.2 Thesis Origins

The Western Cape Province, which is one of nine provinces in South Africa, has experienced exponential population growth, urbanisation and energy demand over the past 20 years. This has seen large volumes of solid waste generation which is putting pressure on waste management in the province (WC - DEA&DP, 2013). Existing waste management policies and regulations only focus on collection and disposal at landfills. However this is not sustainable in the medium to long term due to decreasing landfill space, the environmental implications as well as increasing population growth, waste generation coupled with increasing disposal costs.

However, in recent years the province has made considerable progress towards improving waste management as well as including integration practices which recognise waste as a resource which can be valorised (WC - DEA&DP, 2013). Interventions such as composting, recycling and material recovery are supported and recognised in various provincial and local government legislation but the same cannot be said for WtE schemes.

1.3 Previous Research and Rationale

There is substantial quantitative research globally as well as in South Africa that analyse different types of WtE technologies including potential of energy generation but there is very limited qualitative research in South Africa[1] which addresses the role WtE schemes can play in tackling both energy poverty and waste management. Also there is limited assessment of the barriers that are hampering the deployment of WtE technologies in municipal areas of South Africa. Below are examples of previous research conducted in South Africa which provide state of the art knowledge regarding WtE in the country as well as other cities on the African continent:

1. *Energy from Waste Water – A Technical Feasibility Study* (Burton, et al. 2009)
2. *Market Based Instruments: A key component of South Africa's Future Regulatory Regime for Domestic Waste Management Legal and Policy framework pertaining to domestic Waste Management* (Mackintosh, n.d)
3. *The Financial Feasibility of Waste-to-Energy Generation in the City of Cape Town* (Purser, 2011);
4. *Waste Matters in Planning: An analysis of the spatial implications of Solid Waste Management in the City of Cape Town* (Chitapi, 2013)
5. *Systems in transition: from waste to resource: a study of supermarket food waste in Cape Town* (Marshak, 2012).
6. *The state of Waste-to-Energy Research in South Africa (van der Merwe, 2014).*

All studies acknowledge the challenges surrounding waste management, energy security and population growth in developing countries, particularly South Africa. The studies are cognisant of different WtE schemes but there is significant variation in focus and approach. Burton *et* al (2009) explored waste streams and appropriate technologies with a focus on waste-water to

[1]This brief literature review presented here focusses only on South African scientific research on waste to energy to provide state of the art overview of waste to energy research related to the research questions under investigation, and to show the research gaps on waste to energy in a South African context. A broader literature review is provided in Chapter Two.

energy generation from a very technical/ quantitative approach. The challenges identified related to waste-water to energy and waste management, included (1) a general lack of research capacity and skills, (2) the need to collaborate and share information between academic, private and public institutions and (3) limited incentives.

Purser (2011) looked at the financial performance of WtE technologies and not the impact they have on a waste management system as well as the infrastructure required for successful implementation. The study also adopted a quantitative approach by conducting a financial analysis of thermal and non-thermal technologies employing financial modelling. Though Purser (2011) did not highlight adoption-related challenges, the study was able to illustrate that WtE technologies are financially viable if considered under the set of assumptions provided. Anaerobic digestion was identified as the best technology, followed by incineration.

Kasozi (2010), Ai (2011) and Chitapi (2013) also addressed waste management and energy supply from an urban planning perspective and addressed mixed methods and qualitative approaches. Their studies investigated the role of and challenges pertaining to the inclusion of better solid waste management systems in urban planning and systems thinking in solid waste management planning but not necessarily in WtE schemes.

Similarly, a review conducted by van der Merwe (2014) on “The State of Waste-to-Energy Research in South Africa” provides an outline of the type of WtE research conducted across South African tertiary institutions in 2014. The review concluded that fields of interest for researchers were anaerobic digestion – for biogas production – followed by fermentation and pyrolysis for transesterification and gasification for syngas production. The research was also spread across various forms of waste feedstock. Furthermore the review acknowledges that WtE research is driven by socio-economic and government directives and several programmes have been put in place to promote more research. However the review does not identify any research pertaining to the challenges faced by local municipalities with regards to adopting WtE schemes.

From the above studies, only two studies briefly discussed the factors hindering local municipalities from implementing WtE as well as discussed the most appropriate technologies for the country. Thus this study explores the barriers to WtE adoption specifically by local municipalities. Identifying these barriers should enable municipalities to put in place measures to promote the deployment of WtE technologies given appropriate conditions in each municipality. The study also aims to provide some basis for further investigation of the feasibility of WtE schemes in South Africa, such as detailed techno-economic and environmental analysis.

1.4 Research Objectives and Questions

This thesis investigates the challenges hindering local municipalities from adopting WtE schemes as an alternative method to addressing waste management and energy supply. The objectives of this thesis are therefore to:

1. Investigate existing waste management methods, challenges experienced and current (proposed) interventions;
2. Investigate local municipalities' efforts to implement WtE schemes and the challenges encountered;
3. Estimate the amount of energy that can be produced by local municipalities from waste and the extent to which the energy gap could be narrowed and;
4. Identify the most appropriate WtE technology that local municipalities could implement.

The complementing research questions for this study are as follows:

1. Are the existing waste management methods efficient and sufficient?
2. Are local municipalities investigating WtE schemes as an additional waste management method and alternative energy production technology? If so, to what extent and what have their experiences been thus far?
3. Is it viable for local municipalities to consider WtE schemes for energy generation?
4. What are the most appropriate WtE technologies that can be implemented by local municipalities in South Africa?

1.5 Scope of Study

The scope of the study is as follows:

1. There are various forms of waste which can potentially be used as energy conversion feedstock. This study only focused on Municipal Solid Waste (MSW) specifically biodegradable waste and combustible waste.
2. With regard to regulatory, institutional and implementing bodies, WtE schemes can be implemented by various organisations and institutions within the public and private space. The study focuses only on the role of the public sector (specifically local municipalities).

1.6 Structure of Thesis

This thesis is structured as follows:

Chapter Two: Sets the scene for understanding the energy and waste management scenario in South Africa. The chapter addresses energy demand and supply issues in the country, and also discusses existing waste management methods, the factors influencing management and the legislative framework.

Chapter Three: Presents a literature review of WtE technologies and illustrates the benefits as well as the regulatory and operational requirements. The chapter also discusses WtE adoption trends in South Africa as well as on the African continent.

Chapter Four: Outlines the research methodology used in the study. The conceptual framework guides the research approach and design. The chapter discusses data collection and analysis techniques, accuracy and reliability of data, as well as limitations to the study and ethical considerations.

Chapter Five: Presents, analyses and discusses the results. The chapter is divided into five sub-sections, which address the key research questions in this study.

Chapter Six: Summarises the key findings of the study as well as recommendations for the challenges identified.

Chapter Two: The Energy Sector, Waste Management and Opportunities for Waste to Energy in South Africa

2.1 Introduction

This chapter provides an overview of state of the energy sector and the potential role of waste as a resource for energy production in South Africa. The aim of the chapter is to establish an understanding of the status of the energy sector and provide a context for the inclusion of WtE schemes in national energy planning.

2.2 State of the Energy Sector in South Africa

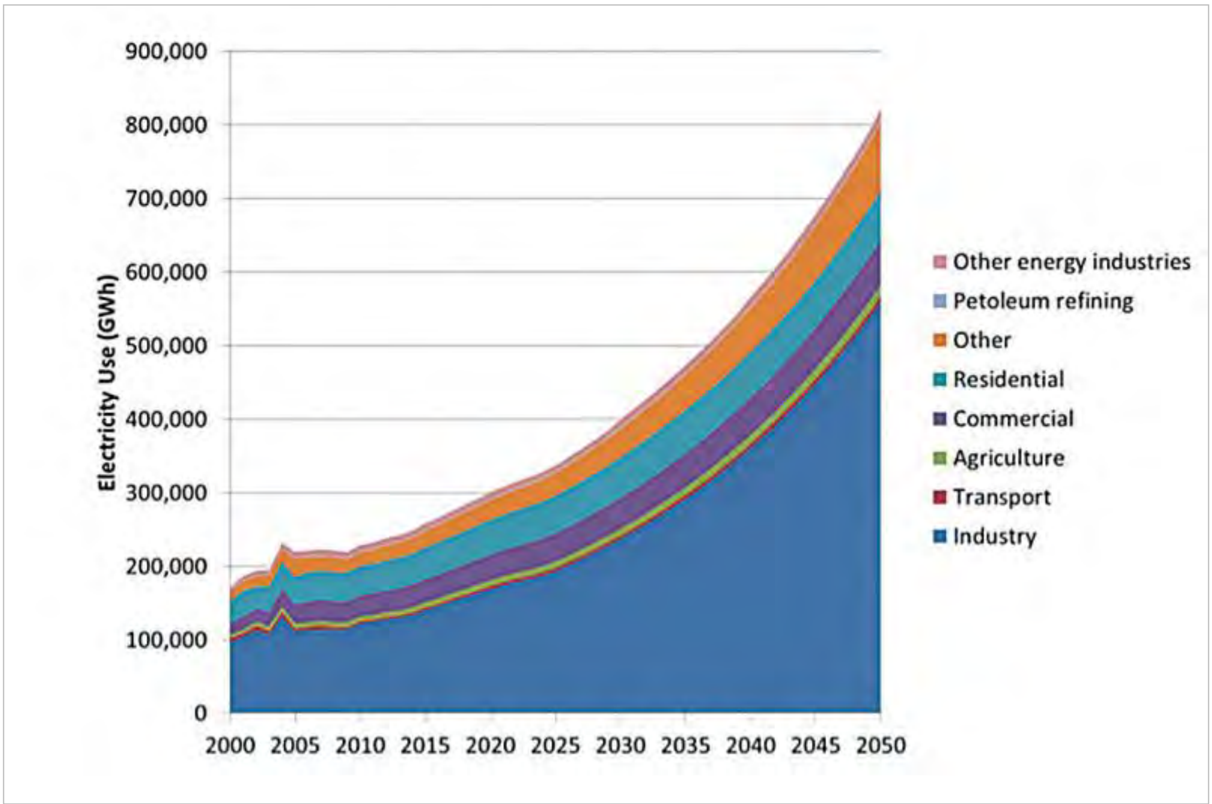
Over the past two decades, South Africa has failed to create the conditions for adequate investments in required energy infrastructure developments (Eberhard, 2014; Kruyt et al, 2009; Department of Energy, 2012a). There is a massive backlog in infrastructure development and an apparent investment paralysis. This is evident in the shortfalls in electricity supply, the growing backlog and deterioration of electricity distribution infrastructure, which has led to rampant load-shedding and consequent energy security crisis and energy poverty across the economy (Kruyt, et al., 2009). The study contends that this is a result of the South African government's inability to provide conducive conditions under which the necessary investments could be developed against a backdrop of increasing electricity demand. This is despite earlier warnings such as those cited in the White Paper on the Energy Policy of 1998. Since the energy crisis in South Africa began in 2008, a majority of Eskom's coal fired power plants have not been performing satisfactorily. This is attributed to challenges such as aging power plants, high costs of operations and maintenance, as well as regulations pertaining to greenhouse gas (GHG) emissions (Calldo, 2008).

The Integrated Resource Plan for Electricity Update (2013) projected South Africa's electricity demand to range between 345-416 TWh by 2030. According to Eberhard (2014), even with the deployment of Medupi and Kusile coal-fired power stations (with a combined capacity of 9.6 GW) South Africa is still unlikely to reduce the electricity supply shortfall. The Minister of Public Enterprises indicated that Eskom would continue rolling out the load-shedding schedule over the next two years (SA News, 2015). This demonstrates the severity of the energy supply challenges facing the country and further demonstrates the need to investigate cost-effective and long term power supply interventions.

According to StatsSA (2015) South Africa's population growth rates have been increasing on a yearly basis. Between 2004 and 2005 the population growth rate was 1.34% per annum, 1.52% per annum between 2010 and 2011 and 1.65% per annum between 2004 and 2014 and June 2015 (Statistics SA, 2015). Thus it is expected that the demand for energy will continue increasing correspondingly (Sustainable Energy Africa, 2013). Furthermore, increasing urbanisation and sprawling makes the challenges of supplying energy to outlying areas and low income peri-urban settlements more difficult (Allen, et al., 1999).

Figure 2 shows the forecasted electricity demand by sector up to 2050. Overall, electricity demand is expected to increase from over 200 TWh to over 800 TWh in the period 2010 to 2050. Most of the increases are expected in the industrial sector (from 100 to almost 600 TWh). Similar increases are expected with oil consumption especially in the transport sector. **Table 1** shows the final energy demand distribution trends from 2010 to 2050. The transport sector's energy demand is expected to be higher than industrial energy demand (44% versus 34%).

Figure 2: Projected electricity demand trends by sector (2000-2050)



Source: Department of Environmental Affairs (2014)

Table 1: Proportion of current and projected final energy demand within different sectors

Sector	2010	2030	2050
Industry	37%	33%	34%
Mining	8%	7%	4%
Agriculture	3%	2%	3%
Commerce	7%	7%	7%
Residential	11%	9%	8%
Transport	34%	42%	44%

Source: Department of Energy (2012a)

On the other hand, South Africa is as a fossil fuel-intensive country (Department of Minerals and Energy, 1998) and this has far reaching implications in terms of sustainability of the energy sector. Over 70% of South Africa's primary energy is derived from coal and about 90% of electricity generation is coal based (Eberhard et al, 2014). Thus to ensure that South Africa's future energy system is sustainable, it is important that the future energy supply be based on cleaner and efficient technologies, desirably from renewable resources. Thus South Africa through the White Paper on Energy Policy (2003) set the target of generating energy 10,000 GWh of electricity from renewable energy resources (mainly from biomass, wind, solar and small-scale hydro) by 2013 (Department of Minerals and Energy, 2003b).

2.3 Energy Supply Programmes and Initiatives

Two main government energy strategies designed to tackle energy challenges in South Africa are the Integrated Resource Plan for Electricity 2010-2030, of 2010 which was updated in 2013 (Department of Energy, 2013), and the draft Integrated Energy Plan of 2012 (IEP) (Department of Energy, 2012a). Both the IRP and draft IEP acknowledge the energy challenges facing the country and aim to address them by identifying medium to long term measures to address the energy deficits including identifying different types of energy sources and technologies, required production capacity, implementation timeframes and investment requirements. These programmes also prioritise increasing renewable energy sources. In 2013, less than 6% of total national energy supply was from renewable sources.

According to the IRP (Department of Energy, 2013), 3.6 GW of electricity will be derived from renewable energy by 2016, a further 3.2 GW by 2020 and 11.4 GW by 2030. The technologies expected to contribute towards electricity generation are: onshore wind, concentrated solar thermal (CSP), solar photovoltaic (PV), solid biomass (forest waste, bagasse and MSW), biogas, landfill gas and small hydro. The renewable energy targets set for renewable energy out of total generation to 2030 are as follows:

- Hydro: 4,759 MW or 12.7% of total capacity;
- Wind: 9,200 MW or 10.30% of total capacity;
- CSP: 1,200 MW or 1.3% of total capacity;
- PV: 8,400 MW or 9.4% of total capacity.

Source: Department of Energy (2012a)

In order to upscale renewable energy deployment in South Africa, the Department of Energy (DoE) introduced the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) in 2011. REIPPPP aims to create opportunities for independent power producers (IPPs) to generate renewable electricity from resources such as solar, wind and biomass. The programme allows project developers to participate in competitive bidding for generation capacity. The IPPs are required to meet specific criteria, particularly localisation, job creation and environmental sustainability (Eberhard et al, 2014; Baker and Wlokas, 2014). The first bidding process was implemented in August 2011 and the – Round Four – was concluded in April 2015 (Department of Energy, 2015). **Table 2** shows capacity commitments that have been made thus far:

Table 2: Status of REIPPPP approved capacity by technology and bidding round

	Round 1	Round 2	Round 3	Round 4
Solar PV	632 MW	417 MW	435 MW	415 MW
Wind	634 MW	563 MW	787 MW	676 MW
Concentrated Solar Power (CSP)	150 MW	50 MW	200 MW	-
Small Hydro	-	14 MW	-	5 MW
Landfill Gas	-	-	18 MW	-
Biomass[2]	-	-	16 MW	25 MW
Biogas	-	-	-	-
Total	1,416 MW	1,044 MW	1,456 MW	1,121 MW

Source: Department of Energy

[2]According to the Department of Energy's IRP 2010-2030 Update, solid biomass includes: bagasse, MSW and forest waste. The report does not indicate the type of technology that would be used but given the consideration for GHG mitigation actions, it is assumed that technologies such as anaerobic digestion would be encouraged more than incineration.

In less than four years, a total of 75 projects had been approved by the DoE, procuring a power capacity of 5,037 MW across all four bid windows (Department of Energy, 2015). It is evident from **Table 2** that the most prominent technologies were solar and wind. Other technologies such as biomass barely had any allocations during the first two rounds but featured marginally in the third round (landfill gas with an allocation of 18 MW and biomass with an allocation of 16 MW). However, the same cannot be said for biogas which had no allocations within that period. Thus there is still scope to explore biogas production through anaerobic digestion in the country and contribute to renewable energy generation. The type of technologies would depend on the municipalities' waste quantities and composition. According to Winkler (2005) it is important for developing countries such as South Africa to diversify the energy supply by developing different renewable energy resources as this improves energy security and access to clean energy while reducing fossil fuel consumption and pollution.

2.4 The potential role of waste as an energy resource

Given the country's energy supply shortfall challenges and the need to increase the share of renewables in the national energy mix, as well as the diversity the technology base, there is an opportunity for South Africa to harness waste to energy as a sustainable energy supply option. Waste to energy (WtE) technologies have been in use for decades in many countries around the world but have recently attracted a lot of attention as a potential renewable energy resource while simultaneously tackling waste management issues (Tan, et al., 2015). WtE allows the conversion of waste material into various forms of energy forms, such as electricity, gas and heat (World Energy Council, 2013). The term has traditionally been associated with incineration but a new generation of WtE technologies is developing; creating a wider platform for waste valorisation into many energy carriers (World Energy Council, 2013). See Chapter Three for more detailed discussion of specific WtE technologies.

There is an opportunity in South Africa to generate renewable electricity from various forms of waste and municipal waste is one such resource that can be utilised. WtE can therefore be incorporated into the broader urban municipality integrated waste management facilities. However, certain types of waste may be suitable for some disposal methods such as recycling and composting while other types may be suitable for energy recovery (Lux Research Inc, 2007). Therefore it is important to assess the waste resource in South Africa's municipalities to evaluate the potential and feasibility of using waste as an energy resource in the urban setting. The following section looks at waste and the factors that influence waste generation and management.

2.5 Waste and Waste Management in South Africa

2.5.1 Definition and Classification of Waste

There is no single definition for waste (Ai, 2011). Public institutions may define it from a governance perspective while the private sector may define it in relation to the products and services they offer. According to Muzenda (2014), waste is typically defined as "an unavoidable by-product of most human activity". The Environmental Conservation Act (Act 73 of 1989) defines waste "as any matter - whether gaseous, liquid or solid" (Republic of South Africa, 1989a)…"originating from any residential, commercial or industrial area, which is superfluous to requirements and has no further intrinsic or commercial value" (CSIR, 2009). The latter part of their definition, *which is superfluous to requirements and 'has no further intrinsic or commercial value'*, is subject to debate. The National Environmental Management: Waste Amendment Act (2014) defines waste as "*Any substance, material or object, that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be discarded or disposed of….., whether or not such substance, material or object can be re-used, recycled or recovered …."*

Waste is divided into two main classes, namely general and hazardous waste, which are further sub classified into smaller categories. As shown in Table 3, The National Environmental Management: Waste Act (59/2008): National Waste Information Regulations (2012) categorises general waste into sub-categories of domestic, industrial and institutional waste. A more detailed discussion of the general waste sources and types is provided in **Table 3**. Hazardous waste is sub-categorised as explosives, flammable liquids and solids as well as corrosives (Department of Environmental Affairs, 2012b).

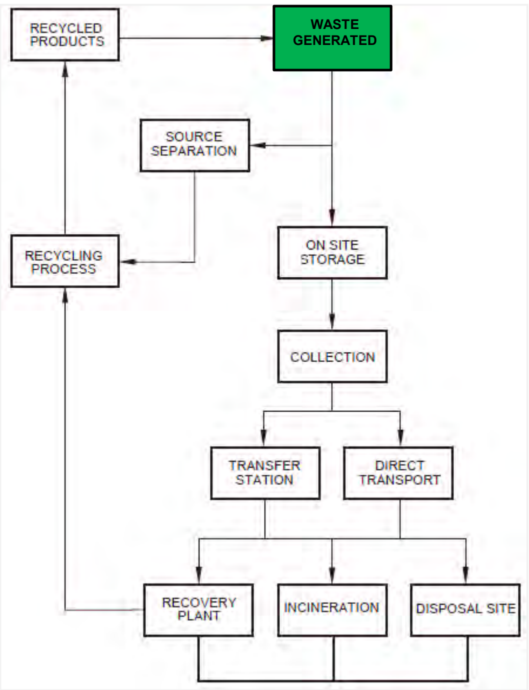
Table 3: General Waste - Sources and Types

Category	Typical waste generator	Types of wastes
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g. bulky items, consumer electronics, batteries oil, tyres) and household hazardous wastes.
Industrial	Light and heavy manufacturing, power and chemical plants	Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes, ashes, special wastes
Commercial	Stores, hotels, restaurants, markets	Paper, cardboard, plastics, wood, food wastes, glass, special wastes, metals, hazardous wastes
Institutional	Schools, hospitals, prisons, government centres	Paper, cardboard, plastics, wood, food wastes, glass, special wastes, metals, hazardous wastes
Construction and demolition	New construction sites, road repair, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, etc.

Source: Muzenda (2014) and CSIR (2009)

It is important to categorise waste as some material are unsuitable for energy generation, (e.g. electronic waste and construction/ demolition waste). Knowledge of the waste sources and types also enables the establishment of appropriate management systems. Traditionally waste management entails the collection and transportation of waste to landfill sites typically found around urban peripheries (Theron & Visser, 2010). It has since evolved to include other stages such as processing, on-site storage, recycling and in some cases, energy generation as shown in **Figure 3**.

Figure 3: The Waste (Management) Cycle



Source: CSIR (2009)

Once waste has been collected either one or both of the following activities occur: it is separated and recycled or it is disposed in a landfill or incinerated. Recycling has been promoted by organisations such as Nampak, Sappi, Mondi, Petco, CONSOL Glass and Collect-a-Can and together with government they have been instrumental in cultivating a recycling culture. The markets for recycling and education programmes are increasingly becoming favourable and considered as an integral part of the waste cycle. Despite these efforts, landfilling is still the more preferred disposal option because it is cheaper and simpler to implement (Muzenda, 2014). The option to incinerate has not been considered as a viable option for South Africa, incineration has not taken off due to the high capital costs involved and associated environmental impacts (CSIR, 2009).

The waste hierarchy is shown in **Figure 4**. The most preferred management options include: prevention, re-using, recycling and recovery – which includes WtE. Disposal and treatment are the least desired techniques because they are dependent on the safest methods of final disposal, methods that are neither harmful to people nor the environment (Ai, 2011; NWMS, 2011; Stengler, 2015).

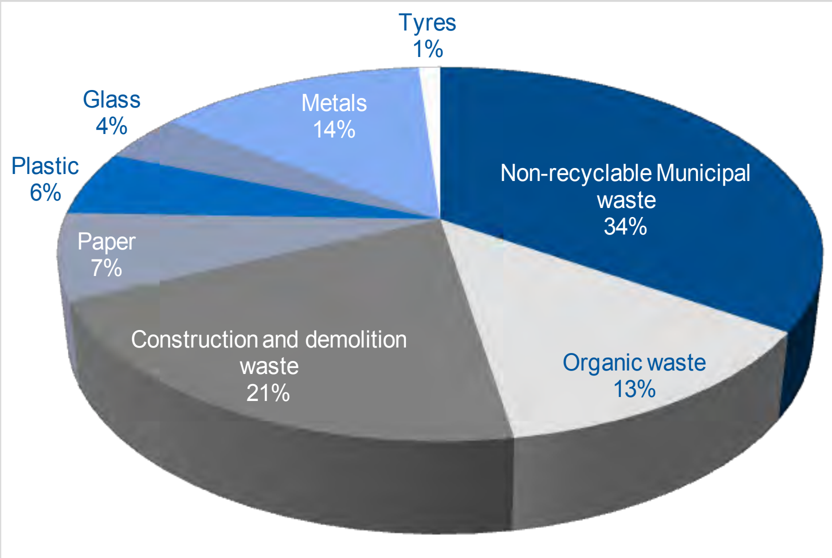
Figure 4: The Waste Hierarchy

Source: Stengler (2015).

2.5.2 Waste Composition and Disposal Methods

According to the National Waste Information Baseline (2012) approximately 108 million tonnes of waste were generated in South Africa in 2011, of which 90% (97 million tonnes) was disposed through landfilling. General waste comprised of 59 million tonnes and unclassified and hazardous waste comprised of 49 million tonnes (Department of Environmental Affairs, 2012a). Waste management in South Africa is thus still heavily reliant on landfilling as a waste management option. **Figure 5** illustrates the waste composition of general waste in South Africa. Thus, the largest component of waste generated comprised of non-recyclable municipal waste (34%), followed by construction and demolition waste (21%), metals (14%) and organic waste (13%). For energy generation, the interesting waste resource includes organic waste, plastic and paper. Useful energy can also be recovered from part of the construction and demolition waste (e.g. demolition wood).

Figure 5: General Waste Composition, 2011



Source: Department of Environmental Affairs (2012a)

Table 4 presents a summary of how various types of waste are typically managed in South Africa in 2011. Gauteng province generated the largest amount of waste and contributed 45% to national waste stream (761 kg/capita/annum) followed by Western Cape which generated 20% of the national waste stream (at 675 kg/capita/annum). As shown in the table below, about 10% of the waste is recycled nationally (about 5.8 million tonnes) (van Rooy, et al., 2013). There is thus scope for transforming part of this waste stream into energy and developing the WtE sector in the country.

Table 4: Waste Disposal Methods (2011)

General Waste (GW) category		**Generated (tonnes)**	**Recycled (tonnes)**	**Landfilled (tonnes)**
GW01	Municipal waste	7 878 564	-	7 878 564
GW10	Commercial and industrial waste	12 111 267	9 325 676	2 785 591
GW20	Organic waste	2 954 461	1 034 061	1 920 400
GW21	Sewage sludge			
GW30	Construction & demolition waste	4 725 542	756 087	3 969 455
GW50	Paper	1 694 752	966 009	728 743
GW51	Plastic	1 278 713	230 168	1 048 545
GW52	Glass	937 869	300 118	637 751
GW53	Metals	3 121 203	2 496 962	624 241
GW54	Tyres	246 631	9 865	236 766

General Waste (GW) category		Generated (tonnes)	Recycled (tonnes)	Landfilled (tonnes)
GW99	Other	36 171 127[3]	-	36 171 127
Total general waste (tonnes)		**59 008 862**	**5 793 271**	**53 215 591**

Source: Department of Environmental Affairs (2012a)

Only 10% of the total waste generated was recycled. The Department of Environmental Affairs (DEA) suggested an annual waste generation growth rate of 1.57% per annum (Department of Environmental Affairs, 2012a) compared to the 2-3% suggested by Feihn & Ball (2005).

2.5.3 Factors influencing waste generation and management

According to a 2013 report conducted by Urban-Econ (CC) and EScience Associates (Pty) Ltd (van Rooy, et al., 2013), waste generation and management are influenced by the following factors:

- demographics – i.e. increasing population, migration and urbanisation rates,
- socio-economic factors – type and growth of economic activities,
- policy issues – e.g. the promotion and implementation of green initiatives such as the 3Rs – reducing, reusing and recycling.

South Africa's growing population and urbanisation patterns have major implications for municipalities in terms of service delivery (Stast SA, 2013; Turok, 2012). Currently, the population is just over 51 million people and the average growth rate is estimated to be 1.6% per annum. At present, over 60% of the population are urbanised and the urbanisation growth rates are higher (1.2% per annum) than the general national population growth rate (City Energy, 2013). Urbanisation is driven by limited economic opportunities in rural areas and the increased urban population generally puts a strain on the urban infrastructure and service provision (Turok, 2012). As the urban population continues to increase, waste generation increases correspondingly and municipalities have to cater for the increased demand for services such as waste management and energy demand. Local municipalities are mandated to provide among other services, waste management within their jurisdictions (van Rooy, et al., 2013).

[3]This waste material comprises mostly of industrial biomass and offers significant opportunities for WtE.

Indigent communities especially find themselves on the periphery of urban areas with limited services such as waste management and electricity supply (Turok, 2012).Some areas (such as informal settlements) are typically without bulk service infrastructure (sewage pipelines and electricity connections) or are inaccessible (e.g. for waste collection). Thus municipalities are overstretched in their efforts to cater for different demands for urban service delivery. The municipalities therefore utilise cheaper and less complex waste disposal methods such as landfilling (City Energy, 2013). Integrated waste management which incorporates conversion of part of the waste stream into energy has not been adequately addressed by municipalities in South Africa.

2.5.4 Legislative Framework

To facilitate the introduction and upscaling of WtE technologies in South Africa, there is need to have supportive policies and regulations. WtE initiatives would contribute to renewable energy production and supply, climate change mitigation and improved waste management.

Currently, there are a number of policies and regulations governing waste management, promotion of the renewable energy sector and integrated waste management practices, as well as sustainable development and climate change mitigation. According to the World Resource Institute (WRI, 2015) South Africa was ranked the 17th largest greenhouse gas (GHG) emitter globally, emitting an estimated 462.60 $MtCO_2eq$ in 2012. Nationally, according to the GHG Inventory of the period 2000 to 2012, the total GHG emitted by the waste sector was 18,773 Gg CO_2eq in 2010 (Musee & Witi, 2014). Emissions from the waste sector increased by 6% from 2000 to 2010 and this was mainly due to increasing emissions from landfills and economic activities (Musee & Witi, 2014).

The South African government recognised the need to address this environmental sustainability impediment and promote renewable and/alternative energy source. Quite a number of energy and waste management policies which are useful in supporting the development of WtE schemes in South Africa. Although there are policies from the late 1980s to early 1990s which govern waste management practices, those promulgated post 2008 provide a platform to consider WtE as an option but do not explicitly refer to WtE. The policies and legislation that address waste management, energy and WtE are listed in **Table 5**.

Table 5: Policy and legislation supporting WtE in South Africa

	Relevant sector		
	Waste management	**Energy**	**WtE**
The Constitution of the Republic of South Africa (1996)	✓	✓	
The Municipal Structures Act (Act No 117 of 1998)	✓	✓	
The Municipal Systems Act (Act No 32 of 2000)	✓	✓	
White Paper: Policy on Pollution Prevention, Waste Minimisation, Impact Management and Remediation (2000)		✓	
Municipal Finance Management Act (Act No 56 of 2003)	✓	✓	
White Paper on Renewable Energy (2003)		✓	✓
The National Environmental Management: Waste Act (Act No. 59 of 2008)	✓		✓
The Energy Efficiency Strategy (2008)		✓	
The Waste Information Regulations (Notice 430 of 2009)	✓		✓
National Policy on the Thermal Treatment of General and Hazardous Waste (2009)	✓		
The New Growth Path Framework (2010)		✓	✓
National Waste Management Strategy (2011)	✓		✓
The National Development Plan, Vision for 2030 (2011)		✓	
The National Climate Change Response White Paper (2011)		✓	✓
Municipal Sector Waste Plan (2011)	✓		✓
The New Growth Path: Accord 4 – Green Economy Accord (2011)	✓	✓	✓
National Strategy for Sustainable Development and Action Plan (2011-2014)		✓	✓
The National Environmental Management: Waste Amendment Act (Act No. 26 of 2008)	✓		

Chapter Three: Literature Review

"The relationship between renewable energy sources and the communities we expect to host them must be appropriate and sustainable and, above all, acceptable to local people" - Owen Paterson.

3.1 Introduction

This chapter discusses global trends and experiences in the development of WtE. It also describes WtE concepts: the technologies, benefits and by-products as well as regulatory and operational requirements.

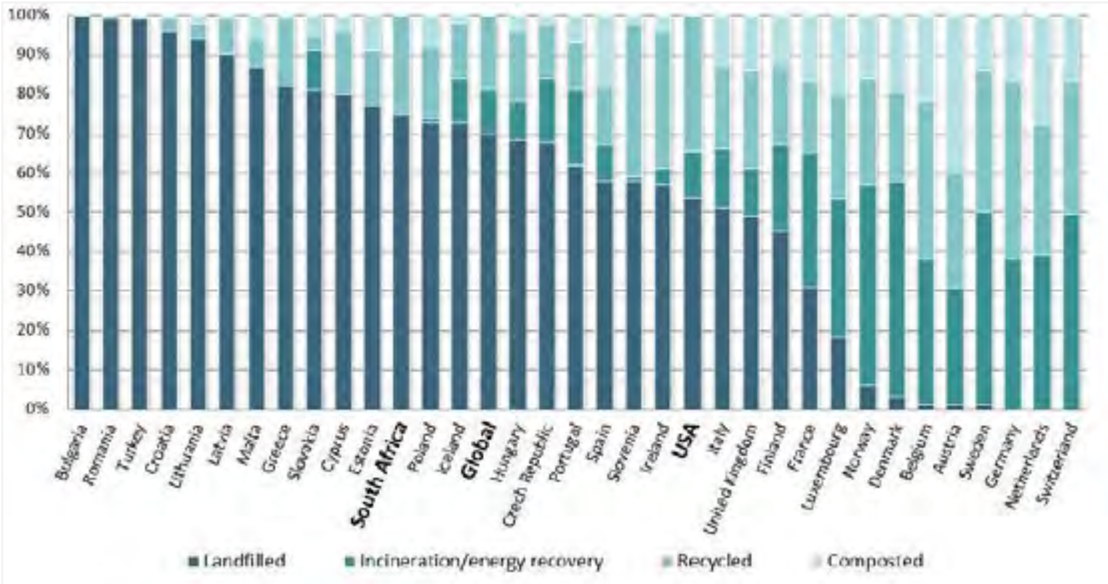
3.2 Rationale for Adopting WtE Schemes

Global MSW generation is expected to grow from about 1.3 billion tonnes of waste per year (World Energy Council, 2013) to about 2.2 billion tonnes per year by 2025 (Oliviera de Medieros, 2012). Hence, waste management is likely to become more challenging as urbanisation continues to increase. This has increased the interest in investigating integrated waste management systems including WtE (Stablein, 2010). Current infrastructure to address waste management (reduce, re-use, recycle or recover waste) in developing countries is not well developed as most municipalities are reliant on landfilling. However, landfilling is not sustainable as landfill sites are depleting in capacity and municipalities are running out of land for landfilling (Amber, et al., 2012; Gumbo, 2013). Also, there are negative environmental impacts such as methane emissions and leaching of toxic waste into groundwater (Oliviera de Medeiros, 2012). However, MSW can be harnessed to contribute to a future sustainable energy mix (World Energy Council, 2013). WtE schemes are already being employed as part of very effective methods of waste management and energy production in various countries across Europe and Asia as well as in America. Data from EuroStat (2010) shows that many European countries are transitioning from landfilling toward recovery.

About 70% of global municipal waste is disposed in dump sites or landfills, and only 11% is treated using WtE technologies. The remaining 19% is either recycled or composted (Department of Science and Technology, 2014). It is evident from

Figure 6 that South African municipalities rely on landfilling as the key waste management approach, followed by recycling. However, there is significant investment in WtE in various countries. Between 2011 and 2012 alone, venture capital and private business investment into the WtE sector increased by 186%, totalling an investment of USD 1 billion(World Energy Council, 2013).

Figure 6: Global waste management approaches by country



Source: Department of Science and Technology (2014) and EuroStat (2013)

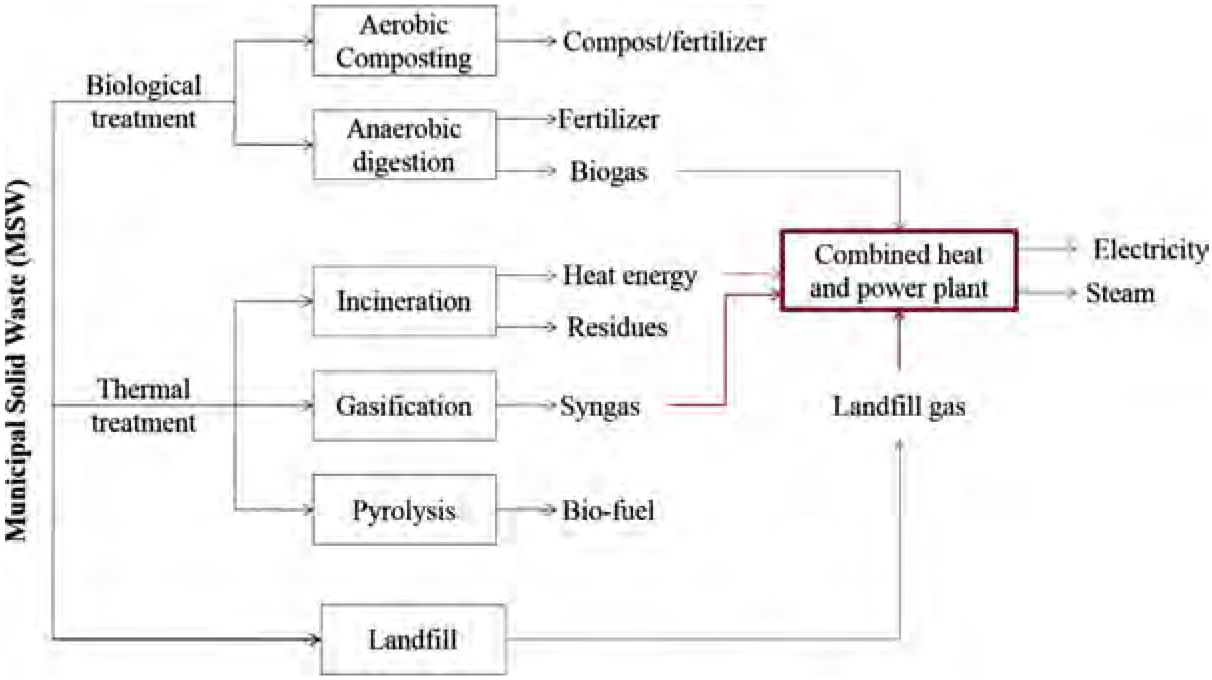
3.3 WtE Technologies

3.3.1 Conversion Pathways

The World Energy Council defines WtE as technologies that comprise of any waste treatment process that generates energy in the form of electricity, liquid or gaseous fuels or heat, using waste as feedstock (World Energy Council, 2013). In the context of municipal waste, there are three main categories for WtE technologies, namely physical, biological and thermal (Faaij, 2006; Tan et al 2015) as shown in **Figure 7**. Thermal conversion of waste to produce electricity and heat includes waste incineration, gasification and pyrolysis. Biological treatment is primarily via anaerobic digestion of waste with the production of biogas. Landfill gas recovery to energy systems (LFGRS) entail CH_4 gas recovery from landfills for electricity and heat generation.

It should be noted that the WtE conversion configuration shown in Figure 7 is an example where heat and power production are key products. However, this configuration depends on the needs and presence of a local market for the various possible energy products, thus different WtE pathways can envisaged and configured where either electricity, heat, gas or combinations can be produced.

Figure 7: Waste to energy conversion pathways



Source: Tan et al (2015)

3.3.2 Biological Treatment

Anaerobic digestion

Anaerobic digestion or fermentation involves the natural biodegradable process of organic material by micro-organisms in the absence of air. This is a biological process that requires specific environmental conditions and bacterial populations to decompose the organic waste to a methane rich biogas, which can be used directly or upgraded to secondary energy carriers (Lastella et al., 2002; Demirbas, 2011).

Anaerobic digestion of biomass waste is a mature technology, which has been successfully demonstrated and widely applied commercially using various feedstocks such as organic domestic waste, organic industrial wastes, manure, sludge, etc. Biogas digesters have for long been deployed in the food industry to process waste water with high loads of organic matter (Faaij, 2006). It has also been used widely in treatment of sewage waste (Asagari, et al., 2011). Digestion is particularly suited for wet biomass materials, and feedstock conversion rates can be as high as 35% depending on the feedstock. However, biogas-to-electricity conversion efficiencies are poor (typically some 10–15%) (Faaij, 2006). Currently large scale and advanced systems for wet industrial waste streams are applied in many countries and co-digestion of for instance manure or sewage and wet organic process residues is especially promising (Faaij, 2006).

Landfill gas recovery to energy systems (LFGRS)

Landfills generate biogas (or landfill gas) when wet organic waste decomposes under anaerobic conditions (Asagari, et al., 2011). Landfill gas recovery is considered a WtE technology when the generated CH_4 (biogas) is captured and utilised for energy generation. LFGRS is well suited for biodegradable organic waste with high moisture content (Faaij, 2006; Tan et al 2015). Thus MSW that has high percentages of un-degradable material (e.g. metal, plastic, glass) decrease the energy production potential of landfills. Methane rich landfill gas from landfill sites makes a significant contribution to atmospheric methane emissions (Oliviera de Medeiros, 2012). In South Africa, this is estimated to be 18,773 Gg CO_2 equivalent in 2010 just from the waste sector (Musee & Witi, 2014). Thus the recovery of landfill gas and its utilisation in electricity and heat has many benefits including GHG mitigation (Tan, et al., 2015).

3.3.3 Thermal Treatment Technologies

Waste incineration (or mass combustion)

Waste incineration is the most common biomass waste-to-electricity conversion technology where fairly low moisture organic waste is combusted in a furnace or boiler under high pressure. The biomass waste requires pre-treatment such as pre-drying to remove excessive moisture before it is fed into a combustion chamber. Incineration is a high temperature process (Yip & Chua, 2008). Electricity is typically generated using steam turbines and some systems can be designed for cogeneration of steam and electricity. Mass burning requires much higher capital costs but have relatively low conversion efficiencies (Faaij, 2006; Akujieze & Idehai, 2014; Tolis, et al., 2010).

Gasification

Gasification is another high temperature process where solid biomass waste is converted into fuel (syngas) under controlled conditions. During gasification, the biomass is combusted with a controlled amount of oxygen to supply a sufficient amount of heat for the predominantly syngas reaction (Arena, 2012). Syngas is mainly composed of hydrogen, nitrogen, sulphur, CH_4 and oxygen – the syngas characteristics depend on the waste feedstock. Although gasification of solid materials has been in practice for many years, its application for biomass is still not fully commercialised. It has also only recently been applied in waste management (Tan et al 2015). The syngas can be fed to a power generation plant for electricity and heat production. Alternatively the syngas can be upgraded to liquid transport fuels via Fischer Tropsch synthesis. The solid by-products of gasification are mainly char and this is commonly disposed of in a landfill (Akujieze & Idehai, 2014; Tolis, et al., 2010).

Pyrolysis

Pyrolysis is a high temperature process which converts waste to liquid (bio-oil), gaseous and solid (char) fractions, in absence of oxygen. Flash pyrolysis (or fast pyrolysis) can maximise the liquid fraction production (up to 70% of the thermal biomass input). However, the bio-oil is corrosive and acidic, and therefore requires special handling. The crude pyrolysis oil can be used for firing engines and turbines, but this may require some modifications depending on the quality of the oil. The oil can also be upgraded but this is at high costs and highly inefficient process. Pyrolysis is largely in the demonstration phase and much less well developed than gasification (Faaij, 2006; Tan, et al., 2015).

3.3.4 Comparison of WtE technologies

The choice of a specific WtE technology is influenced by various factors. These include the waste feedstock characteristics, current and future waste availability, marketability of energy products and by-products, investment costs and environmental sustainability aspects (Tan et al 2015; Sebola, et al., 2014). Feedstock type is one of the fundamental determinants of identifying a suitable WtE technology and the feedstock comprises of waste material that issued as input for energy generation. It can include material such as plastics, organic waste and tyres, among others. Having a sustainable supply of feedstock determines whether the intended energy generation is sustainable as well.

3.3.4.1 Waste characteristics

Feedstock characteristics such as composition, moisture content and particle sizes are critical to the operation of WTE technologies. Biomass waste has typically high moisture content and this vastly reduces the calorific value of the waste in the case of incineration (Patumsawad & Cliffe, 2002). However, this is not a problem with AD systems as water is a necessity for the digestion process. Thus the digestion process is more efficient for feedstock with high water (moisture) content; for instance studies show that high methane (biogas) production rates occur at 60 - 80% of moisture content (Bouallagui, et al., 2003).

Waste type and composition affects the choice of a WtE technology. Some technologies can only accept certain types of waste, and the presence of some types of waste can affect the efficiency of the waste to energy conversion process. Incineration, on the other hand can accept a wide variety of waste (including waste that does not need to be separated[4]) (Faaij et al 1998; McKendry, 2002; World Bank, 1999; Begum et al 2012). Gasification and pyrolysis require the waste to be pre-treated and sized to specific characteristics before the waste can be fed into the conversion plant. On the other hand, AD only uses organic waste streams, and requires organic waste to be segregated from the general waste mix before it can be used in the process. Furthermore, some organic wastes may require pre-treatment before they are used e.g. in AD systems (Shahriari *et al.*2012; Kondusamy and Kalamdhad, 2014; Ariunbaatar *et al.* 2014). Important physical characteristics of waste include:

- Size of waste constituents (e.g. for AD, decomposition of the waste is faster with smaller biomass sizes; thermochemical processes also have feedstock size specifications and this sometimes requires biomass pre-processing to suit the process specifications);
- Density (high density waste indicates high biodegradable organic matter and moisture content and low density shows a high proportion of paper, plastics and other combustibles);
- Moisture content determines the suitability for AD or thermochemical conversion (Patumsawad and Cliffe, 2002) as wet biomass reduces efficiency of thermo-chemical energy conversion as more energy is required to drive out the moisture.

Several studies (Tsunatu et al 2015; Begum et al, 2012; McKendry, 2002; Faaij et al 1998) show that the suitability and energy production potential from waste is also influenced by the chemical characteristics of the waste which include:

- Volatile Solids (volatiles represent the portion of the carbonaceous fuel which is produced during gasification or pyrolysis (Arena, 2012) or the amount of biodegradable solids in the total solids that is useful for AD (Deublein & Steinhauser, 2011)
- Fixed carbon content
- Calorific value

[4]Incinerators can accept mixed municipal solid waste of various sizes such as unsorted domestic and commercial waste (paper, plastic, food waste, etc.); green waste such as garden waste, tree trimmings, roadside cuttings; demolition wood. The proportion of combustible waste and its moisture content affects the efficiency of the conversion process, but in principle mixed waste can be fed into incinerators and inert matter can be recovered and landfilled. There is however a need to consider and install pollution control to clean the flue gas emissions from the process.

- C/N ratio (carbon/nitrogen ratio)
- Inerts, ash/residue content
- Alkali metal content
- Toxicity
- Cellulose/lignin ratio.

For dry biomass conversion processes, moisture content, calorific value, fixed carbon and volatiles content, ash content, and alkali metal content are of interest. For wet biomass conversion processes, the moisture content, C/N ratio, toxicity and cellulose/lignin ratio are of prime concern (McKendry, 2002).The suitable range of these key waste characteristics for the viability of waste to energy recovery for the different technologies is shown in Table 6. According to Faaij et al (1998), the waste needs to be appropriately segregated/ processed/ mixed with suitable additives at site before conversion to make it more compatible with the specific technology. Thus for AD, if the C/N ratio is low, high carbon content wastes (e.g. greens, paper, etc.) could be added; on the other hand if the C/N ratio is high, high nitrogen content wastes (e.g. sewage sludge, slaughter house waste, etc.) could be added, to bring the C/N ratio within the desirable range - See **Table 6**.

Table 6: Suitable ranges of waste parameters for technical viability of WtE schemes

Waste Treatment Method	Basic Principle	Important Waste Parameters	Desirable Range
Thermo- chemical conversion ▪ Incineration ▪ Pyrolysis ▪ Gasification	Decomposition of organic matter by action of heat	Moisture content Organic/Volatile matter Fixed Carbon Total Inerts Calorific Value	< 45% > 40% < 15% < 35% > 1,200 k-cal/kg
Bio-chemical conversion ▪ Anaerobic Digestion/Bio - methanisation	Decomposition of organic matter by microbial action	Moisture content Organic/Volatile matter C/N ratio 25-30	> 50% > 40% 265

Source: Tsunatu et al (2015) and Ministry of Urban Development-New Delhi (2000).

3.3.4.2 Waste Availability

To ensure the sustainability of WtE operations, there is need to ensure that sufficient volumes of feedstock are available now and into the future. It is also important to check if there are any competing applications of the waste and factor that in the projected volumes of waste feedstock available. The availability of feedstock also determines the scale at which the plant can be designed and economically operated. For most technologies, varying volumes of feedstock would greatly reduce plant efficiency, and this would lead to poor technical performance and uneconomic operation (Tan, et al., 2015). For technologies that can use multiple feedstock streams, the impact would be less, although the economics of mobilising the feedstock could be more complex[5].This would entail additional costs associated with waste separation either at source or designated areas and transportation.

3.3.4.3 Marketability

The availability of a ready market for the energy products of a WtE facility is a pre-condition for the viability of the investment. Thus if there is not market for biogas for instance, the energy products of an AD plant could be electricity and heat depending on the scale of the plant. Alternatively, the biogas can be upgraded to synthetic natural gas, liquefied or compressed depending on the market. Different markets for gas include industrial, commercial, domestic and transport (Olsson & Fallde, 2013). An incinerator is viable when there is a market for heat and electricity. Typically, markets for heat are not as readily available in warm developing countries such as South Africa (Tiepelt, 2015) compared to colder climate in developed regions. Proximity to an industrial complex that has process heating needs would therefore be ideal for incineration facilities.

3.3.4.4 Environmental Sustainability

The environmental impacts of different WtE schemes vary and the choice of a technology may be largely influenced by environmental considerations such as GHG emissions, local air and water pollution, etc. For instance, incinerators typically produce air pollutant emissions in the flue gas compared to AD systems (Oliviera de Medeiros, 2012). WtE plants may also pose a health hazard for the surrounding community if it is located close to a community. AD does

[5]Mobilising multiple feedstocks usually entails sourcing such feedstock from various unrelated and distant sources and this includes uneconomic small volume trucking of the waste over long distances; it could also involve some costly pre-processing to ensure the overall feedstock is homogeneous. In addition, it may involve retrofitting/complex design of the plant to accommodate different waste streams (including storage and feeding systems) – this is typical where co-feeding and co-firing of biomass is involved.

not require drying feedstock and has benefits in terms of process heat requirements (McCallum, 2011).

3.3.4.5 Conversion efficiencies

Actual energy production depends upon specific conversion process employed and corresponding conversion efficiency. As shown in **Table 7**, for AD technologies the process energy efficiency of converting biomass waste to biogas varies between 10 and 45% (Faaij, et al., 1998). This excludes further conversion to heat or electricity. Conversion efficiencies of MSW incineration technologies range from 12% for older plants to 24% for the latest plants (Faaij, et al., 1998). The electrical efficiencies are generally low due to high energy consumption of the plant, low steam temperatures, high moisture content of the waste and large inert fractions of the waste (Tsunatu, et al., 2015).

Table 7: Conversion efficiencies of various waste to energy technologies

	Energy conversion efficiency[a]				Energy consumption			
	Electricity efficiency (% LHV)		Efficiency primary energy (% LHV)		Electricity (kWh/ton of waste)		Primary energy (MJ/ ton of waste)	
	Min	Max	Min	Max	Max	Min	Max	Min
Improved incineration (increased steam conditions and coupling to CC)	26	30						
Incineration with CHP; 27% waste heat utilisation assumed	16	21	27	27				
Fluid bed incineration	22	25						
Pyrolysis/gasification	12	22						
Pyrolysis/incineration	16	25						
Waste separation[b]					60	60	230	230
Separation-digestion-incineration	24	28						
Separation-composting-incineration	11	11						
RDF gasification	40	43						
Biomass gasification	35	43						
Composting					70	40		
Anaerobic digestion			10	45				
Co-combustion wood	35	45						
Co-combustion sludge[c]	37	47			6	6	1500	0
Sludge incinerationd							400	400
Wet oxidation[d]	0	0	0	0				
Sludge gasification[d]								
Plastics pyrolysis			83[g]	83[g]				

Source: Faaij et al (1998)

3.4 Benefits of WtE

WtE schemes offer a number of local and global benefits. Firstly, adopting these schemes can address “land use and pollution from landfills, and the well-known environmental perils of fossil fuels” (Lux Research Inc., 2007, p187; Psomopoulos, et al., 2009). They offer an improved alternative to existing disposal methods and promote ‘responsible’ landfilling. According to Stengler (2015), WtE can assist in reducing waste volumes by up to 90% and thus reduce the amount of landfilled waste. Thus the demand for land for landfilling can be significantly reduced (Psomopoulos, et al., 2009). In addition, WtE schemes can produce various by-products such as organic fertilisers and bio-char. The latter can be used for carbon abatement through soil conditioning and for improving soil fertility (Ennis et al 2013; Ghani et al 2013).Furthermore, WtE schemes can also be aligned with national developmental goals such as diversifying energy supply base, reducing energy poverty and generating employment and promoting sustainable development (Psomopoulos, et al., 2009; Mohammed, et al., 2014; Kulati & Bredenkamp, 2012; Mthembu, 2012). **Table 8** summarises the key WtE benefits:

Table 8: Benefits attainable from WtE Schemes

Sector	Benefit/Opportunity
Socio-Economic	▪ Employment opportunities across the value chain ▪ Alleviation of energy poverty ▪ Reduced demand for land used for landfills
Energy	▪ Improved energy security and diversification of energy mix
Environmental	▪ Climate change mitigation (methane capture, CO_2 reduction and abatement) ▪ Organic fertiliser production and soil conditioning
Health	▪ Reduction of diseases that breed in waste piles and detraction of rodents ▪ Potential for reduced local pollution (if managed properly)

(Lux Research Inc, 2007; Mohammed, et al., 2014; Kulati & Bredenkamp, 2012; Mthembu, 2012)

3.5 Pre-conditions for WtE deployment

According to the World Energy Council (2013), various environmental, technical and economic factors hinder the development of WtE technologies. The inconsistent composition of MSW, the complex design of treatment facilities and their emissions are key challenges for WtE deployment (World Energy Council, 2013, p. 7b.2).

To implement the WtE technologies, there is need to have a critical mass of technical expertise and institutional capacity across the value chain. For some technologies, such as basic small scale anaerobic digesters, the technical skills requirements are relatively simpler. However, much more large scale and advanced AD systems and more technically complex technologies such as pyrolysis and gasification require more advanced training to facilitate their establishment and operation (Oliviera de Medeiros, 2012).

Apart from the technical side of the technology, it is important to take into account various environmental aspects such as regulations on toxic flue gas emissions and contamination of groundwater (Hulgaard & Vehlow, 2011). Also there are economic issues that affect the viability of the technology, especially the capital investment costs and its relation to the scale of the plant, plant load factor, the waste composition and availability (World Energy Council, 2013, p. 7b.2).

3.6 WtE Adoption in Africa

3.6.1 WtE Adoption in South Africa

South Africa recognises the challenge of waste management in its Integrated Pollution and Waste Management Policy (DEAT, 2000). In addition, there exist other national policies such as the NWMS (2011) that support integrated waste management planning, waste treatment and disposal, promotion of waste beneficiation, etc. (Department of Science and Technology, 2014). Currently there are no policies that explicitly address WtE, although there is a proposed biogas policy which is under consideration (Qase, 2015). A National Biogas Platform is currently operational and tasked to address critical elements such as:

- government's role: resource assessments and policy framework,
- industry's role: project development, construction, operations and maintenance,
- project financing and permit processing,
- research and training, and
- awareness creation.

Less than 10% of local municipalities in South Africa have operational WtE schemes and existing facilities are mainly landfill gas to electricity schemes (Mthembu, 2012). There is considerable potential for WtE development, especially in Gauteng, the Western Cape and Mpumalanga that have considerable volumes of waste given their population and economic activities (the regions' respective annual per capita waste generation was between 761, 675 and 518 kg) (Department of Environmental Affairs, 2012a). The extent to which this potential can be realised is mainly dependent on a number of factors such as availability of landfill space, supportive policy, availability of finance and technical skills, etc (Pan, et al., 2015). Municipalities are likely to consider biological treatment systems such as landfill-to-gas and anaerobic digestion since they are simpler and require lower investment costs (Munganga, 2014). **Table 9** shows the developments of WtE adoption in South Africa:

Table 9: Existing (Proposed) WtE Schemes in South Africa, 2015

Province	Municipality	Status	Technology	Capacity	Year
Kwa Zulu Natal	**eThekwini Metro Municipality**	**P**	**Landfill GtE**	**7.5MW**	2006/9
Eastern Cape	Elundini Local Municipality	N	-	-	-
Free State	Provincial Government	I	-	-	-
Gauteng	**City of Johannesburg**	**P**	**AD of Waste Water**	**1.1MW**	2012
Gauteng	**City of Johannesburg**	**P**	**AD of Waste Water**	**6.6MW**	**2014**
Gauteng	**City of Johannesburg**	**P**	**AD of Waste Water**	**7.1MW**	**2015**
Gauteng	City of Johannesburg[6]	-	-	40MW	2017
Gauteng	City of Ekurhuleni	N	Landfill GtE	6 MW	2014/16
Gauteng	Midvaal Local Municipality	I	-	-	-
Limpopo	**Greater Tubatse Municipality**	**P**	**-**	**-**	-
Mpumalanga	**Thaba Chweu Municipality**	**P**	**-**	**-**	-
Western Cape	Cape Agulhas Local Municipality	FS	-	4.4MW	2010
Western Cape	City of Cape Town	FS	Landfill GtE	2MW	2015/16
Western Cape	Drakenstein Municipality	FS	Landfill GtE	10MW	2014/16
Western Cape	**George Municipality**	**P**	**Incineration**	**4.4MW**	**2015/16**
Western Cape	Stellenbosch Municipality	FS	Landfill GtE	1.6MW	2015/16
TOTAL GENERATION CAPACITY - PROCURED				**26.7MW**	

I = Inception N = Negotiations FS = Feasibility Study P = Procurement - Procurement refers to the issuing of requests for proposals with draft PPP agreement, receipt of bids and comparison of bids with feasibility study (National Treasury, 2004)

Source: National Treasury (2015) andMthembu (2012)

[6] https://www.environment.gov.za/sites/default/files/docs/wastemanagementflagship.pdf

Between 2011 and 2014 a total of 38 biogas projects were registered by NERSA, the majority of these are located in the rural areas of Gauteng, Limpopo, Kwa Zulu Natal, the Free State and Western Cape. To date there are approximately 700 biogas digesters in the entire country of which 50% are for small scale domestic use, 40% at waste-water treatment works (WWTW) and only 10% are commercial scale (Tiepelt, 2015b).Implementation of such biogas schemes is hindered by factors such as lengthy Environmental Impact Assessment (EIA) applications, government protocol processes and legislative constraints (van der Merwe, 2014).

3.6.2 WtE Adoption in Africa

WtE adoption varies across the African region due to various factors. The rates and quantities of MSW generated on the African continent differ in accordance with local economies, urbanisation and population, level of industrialisation, lifestyles and waste management systems of the various countries (Simelane & Mohee, 2012). **Table 10** shows some African countries with WtE schemes and the installed capacity.

Table 10: Existing (and Proposed) WtE Schemes in Africa

Country	City	Year	WtE Scheme	Power Generation	Waste(t)
Mauritius	La Chaumiere	2013	Ultra-High Temperature gasification	20MW	300,000p.a
	North East & Central	2017		36MW	1,300p.d
Ethiopia	Addis Ababa	2013	Anaerobic (landfill GtE)	50MW	350,000p.a
Cameroon	Yaoundé	Proposed	-	100MW	
South Africa	Kwa Zulu Natal, Gauteng, Western Cape	2006 - 2015	Anaerobic (landfill GtE)	26.7 MW	108, 000, 000p.a
Kenya	Nairobi (Dandora)	Proposed	Anaerobic (landfill GtE)	70MW	3,000p.d
Ivory Coast	Abidjan	2009	Anaerobic (landfill GtE)	30MW[7]	200,000p.a

[7]http://www.unep.org/pdf/Sub-SaharanCDMProject-List.pdf

Country	City	Year	WtE Scheme	Power Generation	Waste(t)
Ghana	Accra	2014	Anaerobic (landfill GtE)	6MW[8]	270,000p.a
	Accra	2014	Anaerobic (landfill GtE)	10MW	360,000p.a
Nigeria	Lagos (Olusonsun)	-	Anaerobic (landfill GtE)	25MW	10,000p.d
TOTAL (POTENTIAL) GENERATION CAPACITY				**373.7 MW**	

GtE - gas-to-energy *p.a - per annum* *p.d - per day*

Source: Gumbo, 2013; EEPCo, 2013; Adeyemi, 2014; Otieno, (2013)

As shown in **Table 10** significant WtE capacity is being developed in Africa. It is also evident that there are more large scale WtE projects in other African countries compared to South Africa. Most of the WtE schemes involve landfill gas recovery. There is limited information on the specific projects to evaluate the successes and challenges encountered in each of the countries.

3.6.3 Role of Local Municipalities in promoting WtE Adoption

In most cases, waste management is part of the local municipalities' administrative responsibilities as it is part of their mandate to collect, process and dispose waste. According to Simelane & Mohee (2012) municipalities could stimulate and spearhead integrated waste management initiatives and invest in pilot projects that demonstrate novel approaches to waste management including waste to energy schemes. The fundamental and underlying driver for integrated waste management in municipalities should always be geared to reduce, re-use, recycle and recover waste (Ai, 2011; Tabasová, et al., 2012; Department of Environmental Affairs, 2012b). This implies strategies for diverting waste from landfilling, especially organic matter from landfills and redirecting it to anaerobic digestion plants, promoting recycling and reusing waste (Oliviera de Medeiros, 2012).

[8]According to Gumbo (2013) installed capacity of WtE projects in Ghana were 6MW in 2014. An additional 10MW was under construction

However, according to Ai (2011), most waste management policies in developing regions still focus mainly on immediate, local, and short-term waste solutions than considering innovative and economically viable waste management strategies (Ai, 2011). Local municipalities can play a significant role in the development and deployment of WtE technologies. The role of municipalities is further elaborated in Chapters Five and Six.

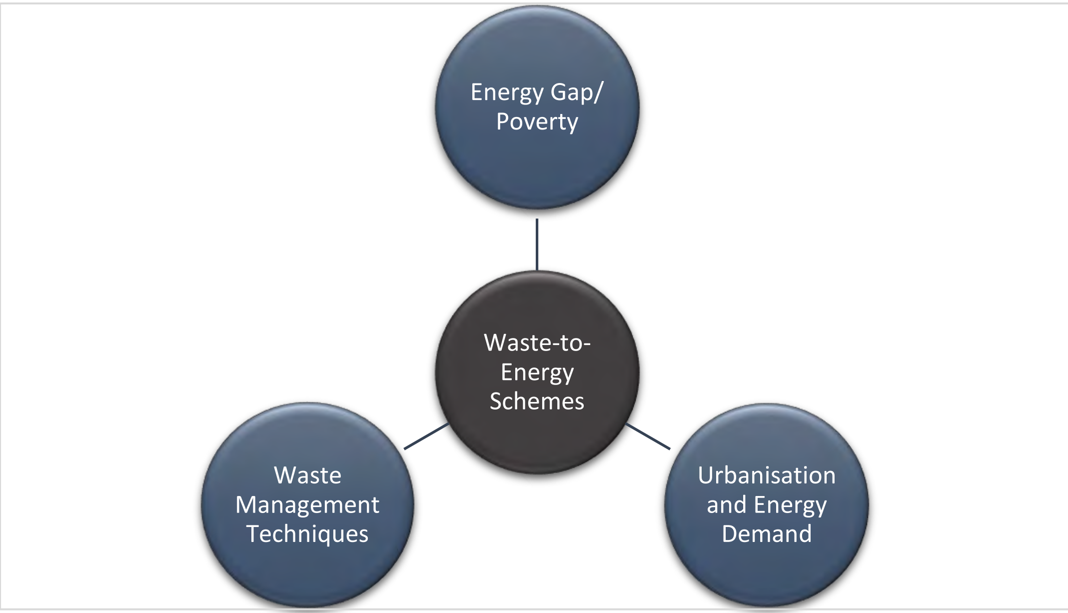
Chapter Four: Research Methodology

"Research is to see what everybody else has seen, and to think what nobody else has thought." - Albert Szent-Gyorgyi

4.1 Conceptual Framework

The conceptual framework presented below gives the underlying rationale and approach to the research. As shown in **Figure 8**, the conceptual framework is premised on the three pronged issues of (1) tackling energy supply shortfalls and reducing energy poverty, (2) addressing challenges of urbanisation and population growth rates and corresponding urban service delivery challenges (3) developing integrated waste management strategies including WtE schemes. South Africa is addressing all three challenges to facilitate sustainable development and improved welfare of its citizens.

Figure 8: Conceptual Framework of the Research



One: Energy Gap/Poverty:

As discussed earlier, South Africa has been experiencing an electricity supply shortfall since 2008 and this has led to sporadic load shedding with negative impact on the economy and at individual household level (Krupa & Burch, 2011). This occurred during the global recession, leading to further aggravation of the economy (Sebitosi & Pillay, 2008).

The power shortfalls are being experienced despite interventions such as the IRP (2010), the draft IEP (2012) and REIPPPP – most of these strategies are yet to be implemented. Furthermore, the multi-year price determination (MYPD) for Eskom was initially implemented at 8% per annum until 2016 but has since changed to 16% per annum in order to build new generation capacity to increase supply (Eskom, 2012). There are concerns that the country's economy is likely to be negatively impacted and particularly low income households, who cannot afford the higher electricity tariffs and rely on dirty and dangerous fuels such as paraffin (Franks and Prasad, 2014).

Two: Urbanisation and Energy Supply shortfall

The energy gap/ poverty is expected to worsen with increased urbanisation and population growth (Madlener & Sunak, 2011; Li & Lin, 2015).According to the UN Habitat, Africa's urban population is expected to increase by an additional 20% by 2050 (United Nations, 2013). This phenomenon brings about a wide range of challenges relating to service delivery including energy supply. Madlener and Sunak (2011) state that rapidly emerging megacities in Africa are likely to encounter a paramount challenge relating to sustainable urban development and energy provision. With economic growth and increase in incomes, large urban populations are expected to push energy demand to higher levels and in the process increasing the supply shortfalls if corresponding supply infrastructure is not developed concurrently (Selle, 2010). Sustainable Energy Africa (2013) and the Department of Cooperative Governance and Traditional Affairs (2013) identified the following factors that influence South Africa's current urban energy transition:

1. *Sprawling, low density cities and Apartheid-based urban layout*
   This makes it difficult for the government to deliver basic services. The further away a settlement is, the more expensive it becomes to provide the necessary infrastructure such as grid-electrification and waste collection and disposal.
2. *Steady urbanisation rate and large-scale low-income housing programmes*
   Low-income housing programmes are not designed to facilitate households' access to sustainable supply of energy. In many cases, the housing programmes are designated for land on urban peripheries because it is cheaper and take on the form of free-standing dwellings.
3. *Underexploited low cost and poor adoption of renewable energy alternatives*
   Only 3% of South Africa's total electricity supply is derived from renewable energy through the REIPPP Programme.

Three: Waste Management Techniques

As noted earlier, South Africa disposes its municipal waste in landfills and dump sites. Integrated waste management is not fully operationalised and municipalities face many challenges with regards to waste management especially the scarcity of land for landfilling. Waste valorisation is yet to be implemented widely and especially opportunities around WtE. According to Ai (2011) current waste management practices are reactive in nature and mostly focus on short-term impacts as well as "end-of-pipe solutions" (Ai, 2011). Thus an integrated waste management strategy which addresses the various challenges facing municipalities could include WtE with many socio-economic and environmental benefits.

(This study therefore assesses whether WtE schemes have the potential to address the aforementioned)

4.2 Research Approach and Design

4.2.1 Research Approach

Due to the nature of the research objectives and questions, the research comprised of a mixed methods design. Mixed methods approach combines aspects of qualitative and quantitative methods and entails adopting a research strategy that uses more than one type of research method (Brannen, 2008). Despite historical controversies such as the "Paradigm Wars" between constructivism and positivism[9], (Lincoln & Guba, 1985; Bergman, 2008), there are benefits of using the mixed methods approach. Firstly, researchers no longer have to find creative ways to explain how they explore the multiple and co-constructed realities within and between interviewers and interviewees (qualitative) or assume that the responses to a survey are directly connected to a single and accessing reality (quantitative) (Bergman, 2008). Secondly, it encourages researchers to be innovative and promotes interdisciplinary research, catering to the growing strategic and practical oriented research (Brannen, 2008). Mixed methods research still requires elaborate explanation regarding its purpose, methods, how and for what purpose results from different methods are combined. It cannot bridge a gap between constructivism and positivism let alone replace well-designed mono-method designs. Instead, mixed methods research provides an alternative design (Bergman, 2008). Also Gelo, et al. (2008) suggest that mixed methods research should be placed along a qualitative and quantitative continuum.

[9]Constructivism is based on how knowledge and learning are acquired through human interaction and the construction of an individual's own perceptions and positivism is based on how knowledge is acquired through experience and empirical evidence.

4.2.2 Mixed-Methods Research Designs

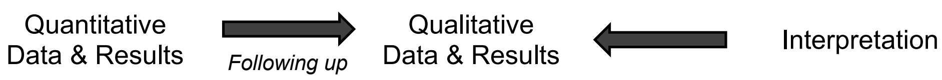
Mixed method design can be classified into two categories: the purpose of the design is to merge qualitative and quantitative data concurrently; and to have one type of data build on or complement the other type of data. Based on the research needs and objectives, one or a combination of four mixed method research designs can be selected, namely (1) Triangulation, which falls within the concurrent research category and (2) Explanatory, (3) Exploratory and (4) Embedded, which all fall within the sequential research category (Cresswell, et al., 2008).

1.) Triangulation Design

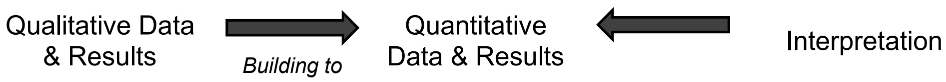
Triangulation comprises of a one-phase design whereby quantitative and qualitative data are collected and analysed concurrently and are then combined to develop an understanding or compare different results illustrated below. It is the most popular of the four but also the most challenging.

For explanatory and exploratory design, qualitative and quantitative data collection is implemented over two phases. Embedded design entails collecting qualitative data before or after an intervention as illustrated below. Researchers use the data collected before the intervention to help recruit or select participants**.**

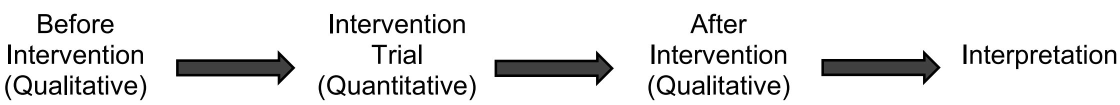
2.) Explanatory Design



3.) Exploratory Design (Chosen for this study)



4) Embedded Design



4.2.3 Research Approach and Design Chosen

The mixed method approach was chosen because it catered to both the qualitative and quantitative aspects of the study and is also useful given the interdisciplinary nature of the study. The Sequential Research Design, specifically the Exploratory Design, was selected to explore the phenomenona of South Africa's energy supply shortfall and the country's current waste management methods. The research design was chosen because it investigated conditions, attitudes and characteristics of animate and inanimate dynamics that have contributed to the current status quo with regard to key issues being investigated. It explored the relationships between energy supply and energy poverty, waste management and WtE schemes (*providing qualitative data and results*). This step then contributes to the '*quantitative data and results*' step whereby calculations can be made to determine the potential energy generation from waste. The '*interpretation*' step seeks to determine whether energy generated from waste can make a significant impact on energy demand and energy poverty alleviation.

4.3 Population and Sampling

It is common to have different samples and sample sizes when combining qualitative and quantitative data because the data is collected for different purposes (Daniel, 2012). When identifying a sample for sequential designs, issues arise regarding selecting the same or different participants for the two phases. With regard to the sample size, the qualitative and quantitative sizes may be unequal depending on the nature of both research designs (Daniel, 2012). Qualitative research tends to generalise a population while quantitative aims to provide an in-depth understanding of a small population (Daniel, 2012). According to Cresswell and Plano Clark (2007) it is not necessary for a sequential design to have a sample that is equal in size. With exploratory design, respondents in the first phase of data collection are usually not the same as those in the second phase. Selecting participants for the second phase tends to create problems because it is dependent on how the researcher carries out the first phase and whether the procedures of doing so are followed accordingly. However, researchers can choose participants (for the second phase) if there is a combination of strategies that builds on the results (Cresswell, et al., 2008). In this study, the same sample used for the first phase was used for the second phase because the sample was applicable for both[10].

[10]In this case, the researcher did not encounter problems with the first phase, thus it was simple to apply for the second phase.

Phase One: Qualitative Sampling

Population Selection

It is important to clearly define the target population to eliminate any unambiguity before making sampling choices (Daniel, 2012). The study focused on six local municipalities in the Western Cape. These included one metropolitan municipality (which is the City of Cape Town Metropolitan Municipality) and five district municipalities, which comprise of 24 local municipalities (The Local Government Handbook, 2015) as shown in **Table 11**. The province has a population of approximately 5.8 million people (about 11% of South Africa's national population) and is ranked the fourth largest province in the country in terms of surface area and population (Stats SA, 2012). The province had the second highest annual in-migration nationally (432,790) as well as internationally (113,873) (Stats SA, 2012). This region was selected based on the criteria which include population dynamics, accessibility to conduct research and potential to implement waste to energy schemes. The latter was determined by conducting an initial review and identification of the municipalities with planned WtE activities (as well as significant potential for WtE), based on publicly available information. Physical access was also a key determinant for selecting the municipalities as this would facilitate face to face interviews. But due to various factors including the schedules of some of the participants, some of the consultations had to be done virtually.

Table 11: Population - Western Cape Municipalities

District Municipality	**Cape Winelands**	**Central Karoo**	**Eden**	**Overberg**	**West Coast**
Local Municipality	Breede Valley	Beaufort West	Bitou	Cape Agulhas	Bergrivier
	Drakenstein	Laingsburg	George	Overstrand	Cederberg
	Langeberg	Prince Albert	Hessequa	Swellendam	Matzikama
	Stellenbosch		Kannaland	Theewaterskloof	Saldanha Bay
	Witzenberg		Knysna		Swartland
			Mossel Bay		
			Oudtshoorn		

Source: The Local Government Handbook(2015)

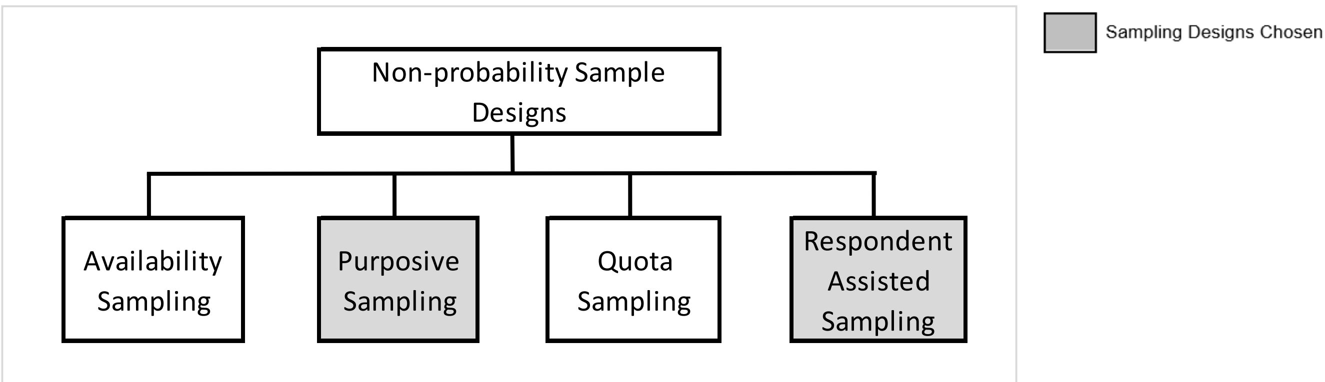
Sampling and Sample Size

Daniel (2012) defines sampling as “the selection of a subset of a population for inclusion in a study”. When done properly, it can save resources such as money and time simultaneously providing useful and reliable data. Although mixed method research design was used in this study, a non-probability sampling approach was adopted instead of a mixed methods sampling technique. Probability sampling means that every element in the target population is given an equal chance of being selected and non-probability sampling does not give all elements a chance to be selected (Daniel, 2012). Thus the findings cannot be extrapolated from the sample to the population.Non-probability sampling also allows the researcher to select a sample/participants based on intuition particularly in instances where the study is interested in specific members of the population. Probability sampling thus becomes inconsistent with the research objectives. This formed the basis on which non-probability sampling was chosen. Additional reasons for selecting this method include:

1. It allowed the researcher to target specific elements of the population;
2. There was no need for representative sampling;
3. It was useful in cases where it was difficult to locate population elements;
4. It was useful given the scattered population;
5. It took cognisance of extremely limited resources such as finances and time.

Although non-probability sampling offered the researcher flexibility, a specific type had to be chosen. There are four major types – see **Figure 9**:

Figure 9: Major Types of Non-probability Sampling



Source: Daniel (2012)

A combination of purposive and respondent assisted sampling designs was chosen. Purposive sampling enabled the researcher to select elements from the target population based on their fit with the purpose and objectives of the study as well as specific inclusion criteria. Due to their sizes and characteristics, not all the 24 local municipalities could be included in a study of this nature given the limited resources and time limitations. A total of five local municipalities were identified, namely:

Local Municipality	**Municipality Type**
▪ City of Cape Town Metropolitan Municipality (CoCTMM)	A (Metropolitan)
▪ Cape Agulhas Local Municipality (CALM)	B3 (LM with a small town or towns as an urban core)
▪ Drakenstein Local Municipality (DLM)	B1 (Secondary City)
▪ George Local Municipality (GLM)	B1 (Secondary City)
▪ Stellenbosch Local Municipality (SLM)	B1 (Secondary City)

Source: (The Local Government Handbook, 2015)

The municipalities were purposely selected based on the following reasons:

1. They are highly populated and urbanised geographical areas, and thus have potential to generate large quantities of waste, one factor that impacts the viability of WtE schemes;
2. They are either investigating or working towards implementing WtE schemes, meaning that they are in a favourable position to discuss factors impeding full and successful adoption – which is the main research objective;
3. They are in close proximity to the researcher in terms of time and financial resources. As noted above, this was one of the pre-conditions for selecting the municipalities. However, in some cases physical meetings were not possible for instance due to unavailability of respondents. Telephonic and email consultations were therefore used in such cases.

Although Cape Agulhas LM has a relatively smaller population, it was included in this study as the municipality is investigating or working towards implementing WtE schemes –the second criterion. This means CALM would have relevant experience to share regarding factors that impeding adoption of WtE technologies. It also provides an opportunity to investigate if challenges experienced in larger municipalities differ from those in smaller municipalities and how this would affect the implementation of WtE schemes in both types of municipalities.

Within these municipalities, the heads-of-department or directors of the Solid Waste Department were selected as potential respondents. They were selected as they are likely to be the most knowledgeable about past, current and future activities relating to the research questions. It was assumed that they would be in a position to assist with 'respondent-assisted-sampling', which entails selecting elements from a target population with the assistance of previously selected elements (participants). It afforded an opportunity to identify additional municipalities which had not been identified by the researcher as well as additional key stakeholders to engage. Additional participants that were identified through the responded-assisted sampling included: two private sector businesses which are operating in the waste management and WtE field, namely Anaergia (Pty) Ltd and Jan Palm Consulting Engineers (Pty) Ltd as well as the GreenCape Initiative, a sector development agency. These organisations offered a non-governmental perspective in terms of how they address WtE related activities.

Phase Two: Quantitative Sampling

As per the exploratory research design, phase one comprises of qualitative data and results. It addresses the first two research questions: (1) *given the status quo of how waste is currently managed, is there a need or any consideration for local municipalities to adopt waste-to-energy technologies as an additional waste management method? If so, at what rate? (2) Have there been any attempts by local municipalities to adopt waste-to-energy technologies? If so, to what extent and what has been the outcome?* The quantitative sampling required is to some extent dependent on phase one yet very specific to the municipalities selected. It mostly comprises of various data bases, specifically waste generation, waste composition and energy supply per municipality. Building on phase one, phase two addresses the last two research questions (3) *what is the feasibility of implementing waste-to-energy technologies and how feasible is it to consider the energy by-product as a sustainable energy supply source? (4) What are the best/optimal/most appropriate waste-to-energy technologies that can be implemented by local municipalities in South Africa*?

4.4 Data Sources and Collection Techniques

Primary and secondary data sources were used to gather the required information. Primary data includes first-hand information (Kumar, 2005) which allowed the researcher to collect information unique to the research and not easily accessible through secondary platforms. This was achieved by conducting interviews with section heads of each municipality's waste management division as well as reviewing feasibility studies of existing WtE schemes. The interview questions were semi-structured so as to obtain specific information as well as to encourage organic conversation for in depth answers. The researcher administered three face-to-face interviews with CoCTMM, DLM and SLM. These face-to-face interviews worked out favourably in terms of time and distance because they were in close proximity to the researcher. The remaining interviews (CALM and GLM) were administered telephonically[11] and via e-mail due to resource constraints and inability to secure appropriate interview appointments with the stakeholders given their busy schedules.

Secondary data sources were used to strengthen and supplement primary data findings. The main sources used include government publications, policies and strategies (Integrated Waste Management Plans, Integrated Development Plans), census databases such as Statistics South Africa and Quantec, mass media such as industry magazines as well as academic material, specifically journal articles and theses. Additional documents included research reports pertaining to waste management and energy supply.

4.5 Data analysis and Interpretation

Exploratory researchers need to determine the type of qualitative results to use in the quantitative stage. Exploratory data analysis was employed by using data from both primary and secondary sources. The data was analysed as follows: an instrument development strategy was used to analyse qualitative results and identify important quotes, develop codes and group codes into themes. Thus the data was subdivided into themes which correlated with the objectives. The qualitative data was recorded in the narrative form and the content was analysed. The quantitative data (socio-demographics, waste volumes, waste characterisation and energy production potential) was captured in Microsoft Excel and analysed accordingly. In the case of contradictory findings, the researcher addressed these by identifying and clearly articulating the differences. The methodology for estimating energy production from waste is given below.

Estimating energy production potential from waste:

The energy production potential from municipal waste depends on waste and conversion technology characteristics. According to Faaij et al (1998) and Dornburg et al (2006), the key parameters which determine the energy recovery potential from waste are:

[11] For two of the five sampled LM, data was collected telephonically. Although this approach could have been used to collect more data from the 24 municipalities in the Western Cape, only the five municipalities met the three selection criteria used in this study. The municipalities either had large volumes of waste generated or was investigating WtE projects to be included in the survey.

- Volumes of waste generated and collected, and seasonal variations,
- Physical and chemical characteristics of the waste, and
- Conversion efficiency of waste to energy technology.

More details of the factors affecting energy generation potential from waste are given in Section 3.4. To calculate the amount of energy that can be derived from waste, the following steps are taken:

Step 1: The quantity of waste generated and collected in each municipality is determined and characterised. Due to the heterogeneous nature of waste composition of each municipality, only three waste streams with potential for energy generation are captured and used: organic, plastic and paper material. (See **Table 12**). This classification is based on the waste classification used by municipalities in the province. It is assumed that the organic waste stream can be separated and directed to AD plants for biogas production and it also assumed the mixed waste including plastic and paper waste can be separated and fed into an incineration plant for electricity production.

Table 12: Organic and combustible waste collected annually by municipality (2010-2014)

Municipality	Waste category	Quantities of waste collected (tonnes per annum)
SLM	Organics	20, 264
	Paper	7, 748
	Plastic	7, 824
DLM	Organics	16, 817
	Paper	17, 722
	Plastic	13, 951
CALM	Organics	-
	Paper	930
	Plastic	634
GLM	Organics	-
	Paper	11, 672
	Plastic	8, 430
CoCTMM	Organics	1, 041, 626
	Paper	534, 167
	Plastic	480, 750

Step 2: The net calorific values (NCV) or lower heating values of each waste stream is determined. The calorific value, which is also known as the heating value, is used to determine "the heat obtained from combustion of one unit of the fuel" (Grubler, et al., 2012, p. 141). Other conversion factors and process efficiencies are also determined for each respective technology. **Table 13** gives typical NCV values for different types of waste:

Table 13: Net Calorific Values of various components of Municipal Solid Waste

Waste component	**Lower Heating Value**	
	BTU/lb	GJ/tonne*
Mixed MSW	**4 800**	**11.2**
Mixed Paper	6 800	15.8
Newsprint	7 950	18.5
Cardboard	7 043	16.4
Junk Mail	6 088	14.2
Magazines	5 250	12.2
Average paper[ξ]	**6 626**	**15.4**
Polyethylene	18 687	43.5
Polystyrene	16 419	38.2
Mixed Plastic	14 100	32.8
Average plastic	**16 402**	**38.2**
Leaves	5 000	11.6
Grass	2 690	6.3
Green Wood	2 100	4.9
Average organic	**3 263**	**7.6**

Source: Voelker (1997)

*Based on conversion factor of 1 btu/lb = 0.002326 MJ/kg

[ξ]Since the volumes of disaggregated waste sub-categories is not available (and very difficult to establish), it is assumed the total waste volumes (per waste class e.g. paper) contain equal proportions of the different waste sub-category streams (in that waste class). Thus the weighted average heating values are simply taken as the average of the heating values with equal weighting for each waste sub-category. This is a simplification and further analysis is recommended to establish more accurate heating values of the waste stream classes.

Step 3: For each technology type (thermo-chemical and biological), the waste quantity data, heating values and conversion efficiencies are used as input is equations given below and the amount of energy generated is calculated using an Excel spreadsheet.

(a) Thermo-chemical Conversion

For thermo-chemical conversion of combustible dry municipal solid waste (assumed to be mainly paper and plastics) into electricity using incineration, the potential energy generation is calculated as follows (Amber, et al., 2012; Ministry of Urban Development-New Delhi, 2000):

Input energy into plant E1 (in GJ) is given by:

$$E1 = NCV \times W$$

Where: *NCV* is lower heating value of waste in GJ/tonne dry

W is waste quantity in tonnes

The output of electrical energy from plant E2 (in GJ) is given by:

$$E2 = E1 \times \eta$$

Where: η is the conversion efficiency of the plant (%). Conversion Efficiency of the incineration plant is assumed to be 20% (Scarlat, et al., 2015).

The output electrical energy from the plant is E3 (kWh) is given by:

$$E3 = {}^{E2}\!/_{3.6 \times 10^{-3}}$$

Note: 1 kWh = 3.6 MJ

(b) Biological Conversion

This conversion process is suitable for biodegradable waste material such as organics (food waste, human waste, manure, sewage, and abattoir waste) (Amber, et al., 2012; Ministry of Urban Development-New Delhi, 2000). Energy production from AD systems can be estimated based on the total solids (TS) or moisture content and the biodegradable volatile solids (VS) in the feedstock as well as on process efficiency and plant specific biogas yield (Karellas et al., 2010). Biogas yield is the amount of biogas generated in an AD process. Biogas yields for different substrates can be empirically determined as m³ of biogas per ton of VS fed and the biogas production volumes are a product of TS, VS and biogas yield (Sosnowski et al., 2003; Karellas et al., 2010).

Total solids (TS) are the amount of solids in the waste feedstock and are an important parameter in AD systems as biogas is only produced from solids (Monnet, 2003). On the other hand, Volatile solids (VS) represent the biodegradable solids component in the total solids and is a measure of biogas production capacity of a particular substrate (Deublein & Steinhauser, 2011). Using typical parameter values for MSW found in literature (including Tsunatu et al 2015; Ministry of Urban Development (India), 2000), potential biogas production (Q in m^3) is estimated using the following formula:

$$Q = Y \times \eta_b \times BDF \times VS \times W \times 1000$$

Where: *Y* is the typical bio-gas yield (assumed to be 0.80 m^3/kg of VS destroyed)

η_b is the typical digestion efficiency (assumed to be 60%)

BDF is the organic biodegradable fraction (assumed to be 66% of VS)

VS is the total organic/volatile solids fraction (assumed to be 50%)

*W*isi the total waste quantity (tonnes)

Total energy recovery can also be given in energy units (GJ) using the following equation:

$$Q_E = Q \times LHV$$

Where LHV is the Calorific Value of biogas (typical values are 20-23MJ/m^3) (Swedish Gas Center, 2012). If the biogas in converted to electricity (and/or heat) then the subsequent conversion process efficiency is taken into account to estimate the potential electricity/heat generation as follows:

$$Q_{CHP} = Q_E \times \eta_{CHP}$$

Where η_{CHP} is the heat and electricity efficiency (assumed to be 30%).

The output electrical energy from the plant is E (kWh) is given by:

$$E = {Q_{CHP}}/{3.6 \times 10^{-3}}$$

These formulas and equations were used to calculate the amount of energy potentially recoverable from different waste streams in different municipalities. The units (kWh and GJ) were converted into MWh using the relevant conversion formulae[12]. The results were able to answer the third and fourth objectives, which explored (1) the potential energy generation and the impact on the energy gap and (2) the most appropriate WtE technology that could be adopted by the selected South African municipalities.

4.6 Limitations to Research

The following constraints were encountered during the execution of the study:

1. Some in-depth qualitative and quantitative information (e.g. most recent figures of waste generation, composition and proposed energy generation capacity) required from participants was not available in time for the study. Participants indicated that the information, in the form of documentation such as pre-feasibility studies and other reports, would only be available publicly after following in-house protocol and cleared by Council. Thus waste generation figures used were not very recent because they are based on older public documents. The most recent figures were not available for all municipalities except Stellenbosch LM (January 2014 to June 2015). The other municipalities were either conducting feasibility studies or preparing municipal documentation which needed council approval. The municipalities also used different waste classification systems and this makes it difficult to make general common analysis (e.g. some municipalities have 'household greens' categories while others included 'organics').
2. Only three face-to-face interviews were administered and the other two were conducted telephonically and via e-mail because of the participants' time constraints and institutional commitments. The participants were not able to answer all the questions and there was no opportunity for organic conversations to gain additional information. Thus information from these respondents may be less informative than the others. Given the study criteria for selecting participating municipalities and resource constraints for conducting the study, there were no other municipalities in the province exploring WtE schemes which could be used to replace these two
3. As noted in section 1.3, there is limited previous research conducted on (1) qualitative aspects of WtE, (2) multi-disciplinary approach and (3) using mixed methods research design. This limited the researcher from having a backdrop from which to develop and/or

[12]http://www.rwe-gasstorage.cz/en/mwh-to-m3-conversion/ and
http://www.asknumbers.com/kwh-to-mwh.aspxn

refine the research strategy. The manner in which the data is analysed, interpreted and presented may be considered unique.

4.7 Ethical Considerations

The evolving research landscape has seen ethical governance and regulations proliferate. This has resulted in more research pertaining to the morality of human conduct. Ethical concerns are prevalent throughout the research process, from conceptualisation and research design to data collection, interpretation, etc. (Schwartz, et al., 2009). Informed consent has been subject of much debate because of the treatment of human research participants (Lincoln, 2009). Ntseane (2009) concurs and states that researchers “must ensure that rights, privacy, and welfare of the people and communities involved in the study are protected” (Ntseane, 2009, p. 296).

Four major frameworks surrounding ethical issues have arisen: (1) the ethical treatment of those with whom, on whom, and for whom (on whose behalf) we conduct research; (2) ethical considerations of the contexts in which research is conducted; (3) ethical considerations for a globalized ethnographic practice; and (4) ethical considerations surrounding data and the preparation of reports, especially in the question of for whom reports are created (Ntseane, 2009). These ethical considerations were followed in conducting this study.

4.7.1 Approval to Conduct the Research

Researchers are obliged to submit an interview strategy to the institution’s ethical review board before undertaking investigations. Before submission the researcher was required to think through issues and ethical quandaries that may arise during an interview and also consulted experienced researchers for guidance. The interview strategy was submitted and ethical clearance was obtained in writing from the Engineering and Built Environment Faculty at the University of Cape Town (See **Appendix C**).

4.7.2 Informed Consent

According to Kvale (2007, p.8) “Ethical guidelines for social science research commonly concern the subjects' informed consent to participate in the study, confidentiality of the subjects, consequences of participation in the research project and the researcher's role in the study”. A letter of consent was sent to the participants before the interviews were administered. Participants were given a chance to read through and probe for additional information before proceeding. The letter introduced the researcher, the purpose of and the research objectives. It also indicated the type and purpose of the questions, how the research will be used, how the data will be stored as well as the duration in which the interviews were to be administered. Participants were informed that participation is voluntary and they could withdraw their consent at any time.

Chapter Five: Analysis and Discussion

“Knowledge is like a garden: If it is not cultivated, it cannot be harvested” African Proverb

5.1 Introduction

This chapter presents and discusses the findings of this study, and these results are presented under four main themes, following the research questions. Section 5.2 provides the socio-demographic profiles of the sampled municipalities while section 5.3 presents findings of existing waste activities in the selected municipalities. The following sub-section summarises the extent to which WtE schemes are being considered and the core of the study: challenges impeding adoption. Section 5.4 presents the potential energy generation from various waste streams and the impact on energy shortfall. Section 5.5 discusses potential WtE technologies suitable for implementation in the selected municipalities.

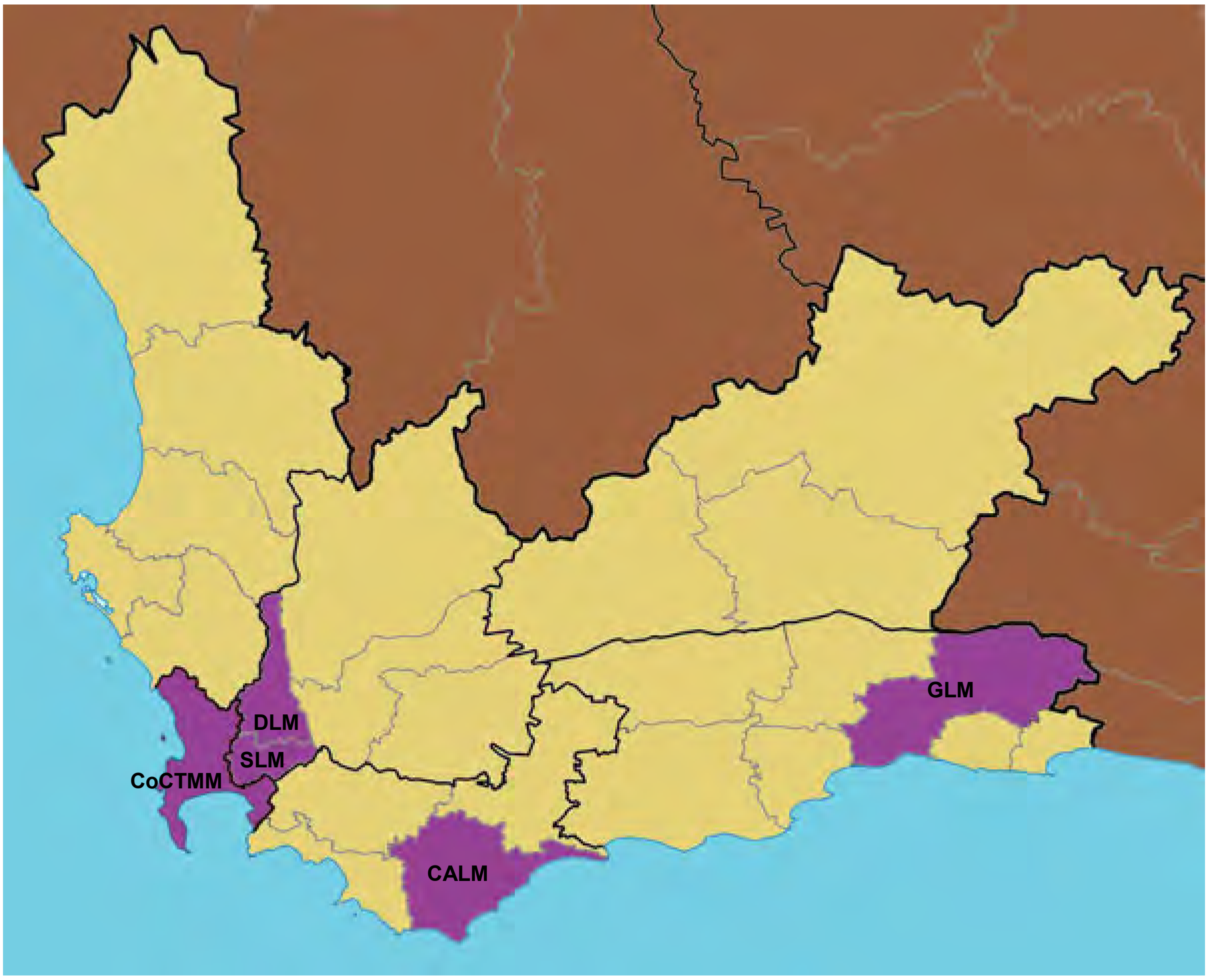
5.2 Socio-demographic Profile

For this study, five local municipalities within the Western Cape Province were selected and analysed. In this chapter the term ‘municipalities’ refers to the municipalities that participated in the study and the term ‘respondents’ refers to the municipalities as well as private and public organisations who participated.

5.2.1 Location of study municipalities

Figure 10 illustrates the locality of the municipalities within the Western Cape Province. The CoCTMM, DLM and SLM are in relatively close proximity to each other as shown on the map, averaging an hour’s drive at most. These municipalities’ boundaries meet at the Kraaifontein Integrated Waste Management Facility, which is operated within the CoCTMM jurisdiction. CALM and GLM are both far from CoCTMM, DLM and SLM as well as from each other.

Figure 10: Locality of Study Areas

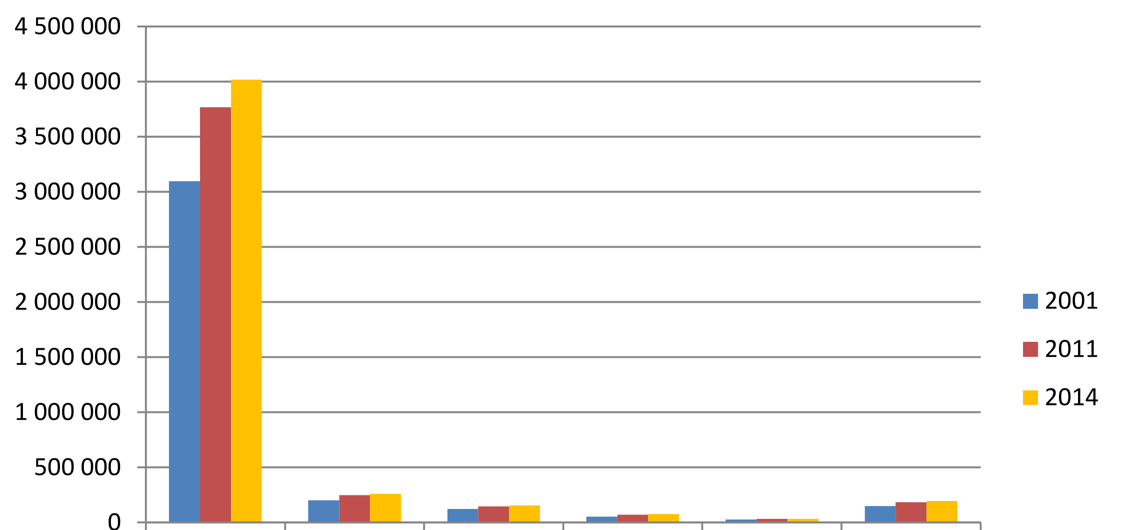


Adapted from Google Maps (2015)

5.2.2 Population Growth

Population size has a direct impact on waste quantities generated. As Gumbo (2013) indicated, waste generation increases as population growth and economic activities increase. Between 2001 and 2014, the average population growth across all jurisdictions was 2.0% per annum. Similarly between 2002 and 2012 the growth rate in national general waste generation was 1.57% per annum (Department of Environmental Affairs, 2012).

Figure 11: Population Growth (2001 – 2014)



	CoCTMM	DLM	SLM	OLM	CALM	GLM
2001	3 095 797	201 101	122 342	54 822	27 277	149 110
2011	3 768 213	246 898	146 954	71 491	32 573	184 852
2014	4 017 038	260 231	154 421	75 572	34 080	194 839

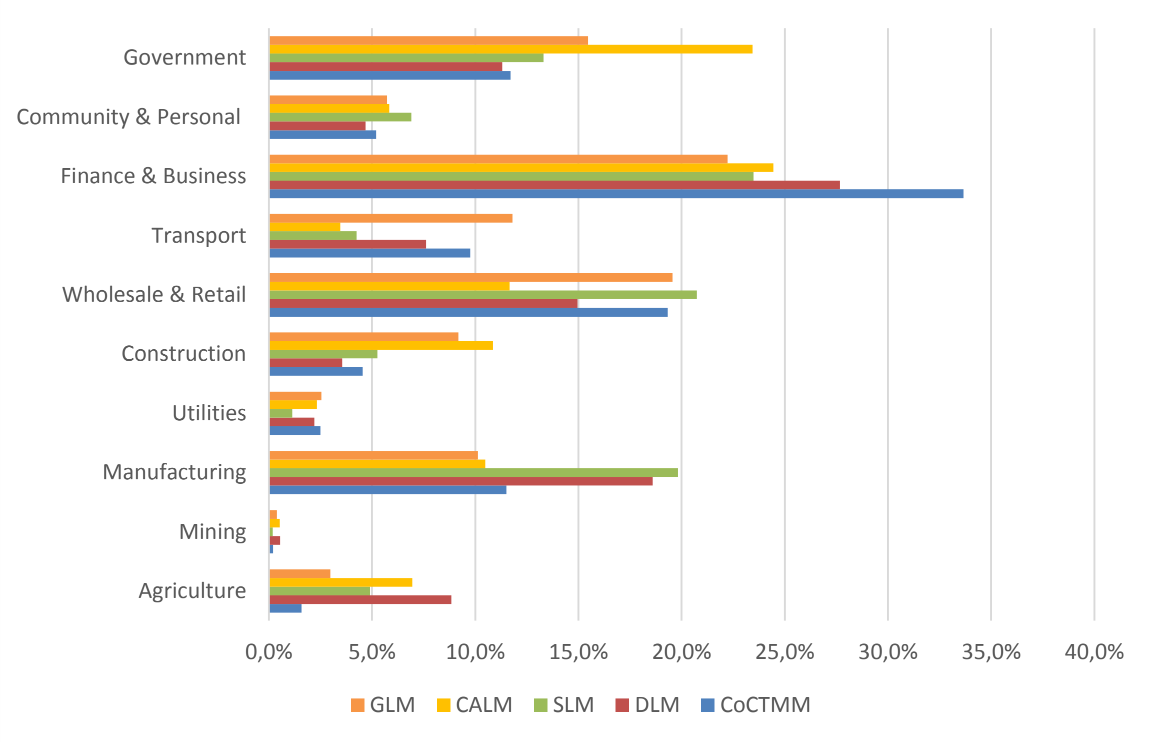
(Quantec, 2015)

As seen in **Figure 11**, CoCTMM is the largest municipality and has experienced a larger population growth (in terms of absolute numbers of people) compared to the other four. The bigger jurisdictions (CoCTMM, DLM, SLM and GLM) maintained a steady increase of 2,0%, similar to that of the provincial population growth during the same period. Considering the large population disparities amongst the municipalities, it is clear that CoCTMM (with a population of 4 million in 2014) generates the most waste compared to CALM (with a population of 34,080 in 2014).

5.2.3 Economic Profile

Being cognisant of the main types of economic activities provides an idea of the type of waste (potentially) generated in each area – See **Figure 12**. This has an impact on the sustainable supply of feedstock; and influences the feasibility and type of WtE technology which can be adopted by the respective municipalities.

Figure 12: Most Prevalent Economic Activities



(Quantec, 2015)

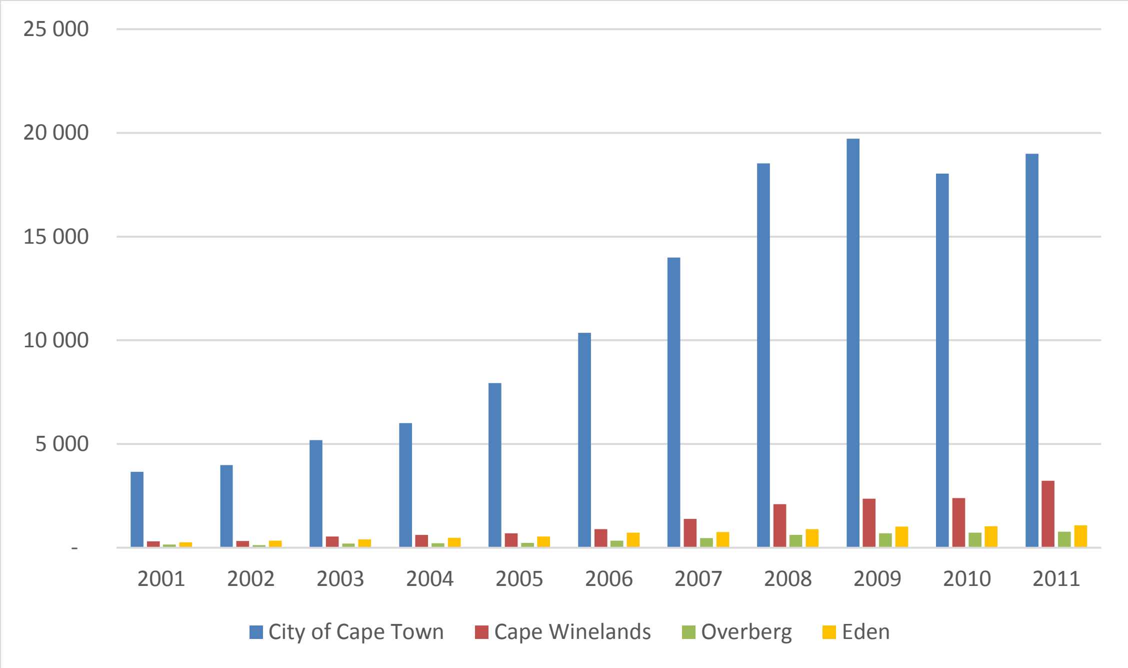
As depicted in **Figure 12**, some of the most prevalent economic activities across all five municipalities include:

1. Finance and Business Services (finance, insurance and business services);
2. Wholesale and Retail (wholesale and retail trade, catering and accommodation services);
3. Manufacturing (food and beverages; wood, paper, publishing and printing; chemical, rubber, plastics; furniture and other manufacturing) and,
4. Government services

5.2.4 Migration Trends

Factors affecting volumes and nature of waste include: the shift from primary to secondary and tertiary activities which leads to broadening of economic activities across more industries; and demographic dynamics including population growth and migration (WC - DEA&DP, 2013).

Figure 13: Migration Trends between 2001 and 2011



(Quantec, 2015)

As shown in **Figure 13**, it is evident that migration trends within the district municipalities have increased over a period of 10 years. District municipalities that experienced the most in-migration were City of Cape Town (CoCTMM), Cape Winelands (DLM and SLM). Eden district (GLM) tends to experience temporary migration which is induced by tourism activities, for example during festivals or holiday season.

5.3 Current Waste Management Techniques

Objective One: Investigate existing waste management methods, and challenges experienced …

5.3.1 MSW Generation and Waste Classification

Waste Generation

Table 14 shows the estimated municipal solid waste generated in the various municipalities per annum over the period 2010 to 2014. It should be noted that the waste generation figures in this table are based on the data provided by the municipalities' Integrated Waste Management Plans (IWMPs), which date between 2009 and 2011. **The IWMPs are in the process of being revised thus more up-to-date figures are still to be determined.** However, some municipalities provided approximate figures for the 2014/15 period based on preliminary results from the feasibility studies.

Table 14: Waste Generation statistics for selected municipalities (2010-2014)

	CoCTMM	SLM	DLM	CALM	GLM
Integrated Waste Management Plans(Year)	2013/14	2010	2013	2011	2013
Waste Generated (tpa)	2,100,000[13]	116, 704	207,377	4,229	80,653

(IWMPs 2009-2011)

Waste generation in the CoCTMM has been fluctuating over the years. According to Coetzee (2015), waste generated in CoCTMM decreased from 2.1 million tonnes in 2007/8 to 1.6 million tonnes in 2010/11 (B Coetzee 2015, pers. comm., 24 April). By the end of 2013/14 the generation figures increased again to approximately 2.1 million tonnes, with a daily generation rate of about 5,500 to 6,000 tonnes. Vice et al (2014) estimated that the Western Cape would generate over 8 million tonnes in 2014 of which 60% would be from CoCTMM (about 2.4 million tonnes). Generally waste generation in the Western Cape has been gradually increasing by about 1% per annum (B Coetzee 2015, pers. comm., 24 April). This may be attributed to the municipality's population growth and development profiles. In DLM's 2013 feasibility study, the total waste generated by the municipality was approximately

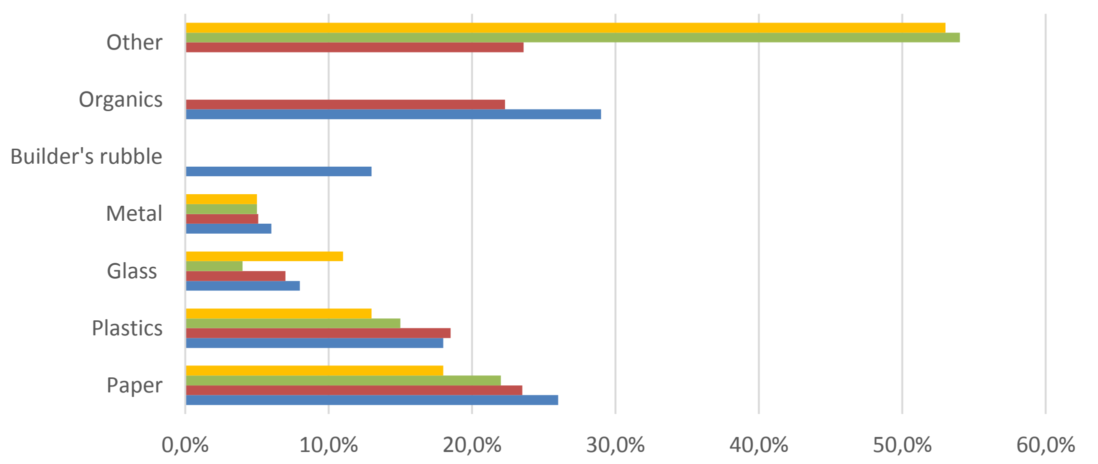
[13] Estimated for the period 2013/14 (B Coetzee 2015, pers. comm., 24 April).

207,377tonnes per annum. The figure was determined based on the data gathered from the weighbridges which were implemented in 2010 at the Wellington landfill site and Paarl transfer station.

Waste classification

Figure 14 shows the distribution of waste generated by type or composition. Most of the generated waste amongst all municipalities other than 'Other' (23.6% - 53.0%) is categorised as 'Paper' (18.0% - 26.0%) followed by 'Plastics' (13.0% - 18.0%) then 'Glass' (11.0% - 8.0%) and 'Metal' (5.0% - 6.0%) – which is closely related to the economic activities in the respective municipalities. SLM is the only municipality which shows a high proportion of 'Builders' rubble' (13.0%) in its waste. Both SLM and DLM show high proportions of 'Organic waste' (29.0% and 22.3% respectively). The other municipalities namely GLM and CALM mostly generate 'Other' type of waste however it is not clear what material comprises of 'Other'.

Figure 14: The Most Prevalent Waste Classifications across the LM – % by Volume[14]



	Paper	Plastics	Glass	Metal	Builder's rubble	Organics	Other
GLM	18,0%	13,0%	11,0%	5,0%			53,0%
CALM	22,0%	15,0%	4,0%	5,0%			54,0%
DLM	23,5%	18,5%	7,0%	5,1%		22,3%	23,6%
SLM	26,0%	18,0%	8,0%	6,0%	13,0%	29,0%	0,0%

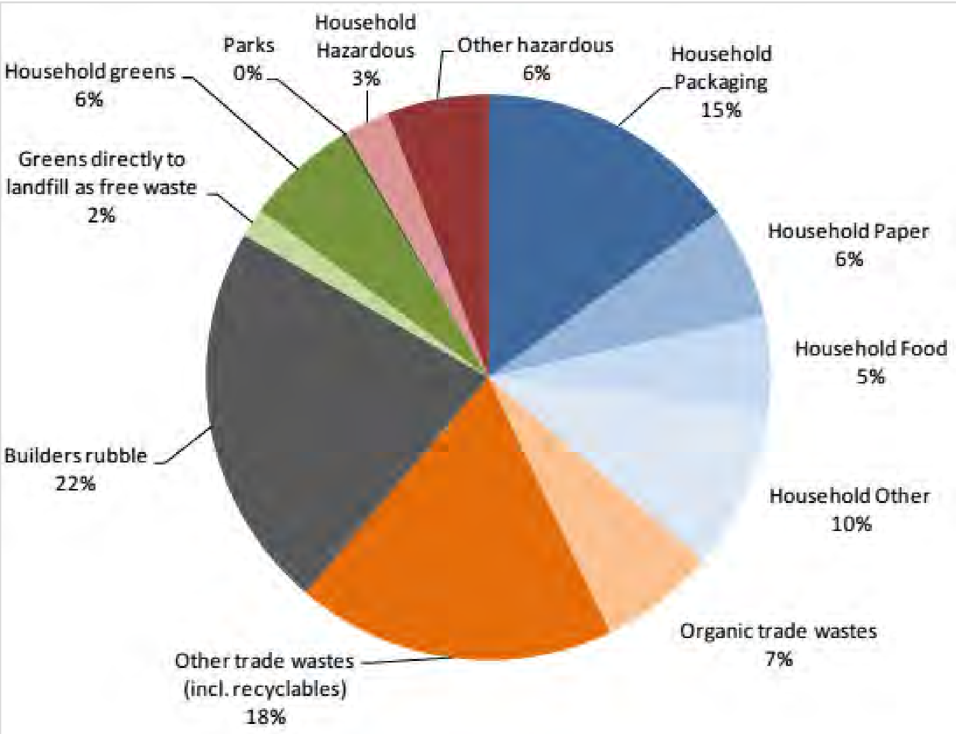
Source: IWMPs (2009-2011)

[14]Due to the different classification systems used by the different municipalities, for GLM and CALM, there is no specific amounts indicated for builder's rubble and organic waste percentages. We assume these are aggregated into the 'other' waste category to make the total 100% of waste generated

CoCTMM waste composition is shown separately in **Figure 15**. It is evident that for CoCTMM, plastics (15% household packaging and 18% other trade wastes), builders' rubble (22%), greens/organics (5% household food, 7% organic trade wastes, 2% greens and 6% household greens) and paper (6%) were the most prevalent type of waste.

The waste in CoCTMM is split between residential (46%), industrial (27%) and commercial (26%).This ratio is expected to remain the same in the short to medium term (Akhile Consortium, 2011). A similar ratio was also observed across the other municipalities where the largest component of waste was also residential. None of the municipalities handle hazardous waste as it is not part of their mandate and is catered for by the private sector[15].

Figure 15: Waste Classifications for CoCTMM % by Volume – 2008/09



Source: Akhile Consortium (2011)

The IWMPs do not use consistent waste classification and characterisation; for example CoCTMM used terms such as 'household greens' and 'organic trade waste' while SLM, DLM, GLM and CALM use general terms such as 'organics'. This makes it difficult to make

[15]Hazardous waste is mainly disposed by the private sector in accordance to the National Environmental Management Acts, amongst others. This type of waste is capital intensive and is delicate due to the nature of the waste, thus municipalities are not positioned to dispose of it.

comparative analysis and generalised recommendations on the feasibility of different types of WtE technologies.

5.3.2 Existing Waste Management Methods

Traditionally, local municipalities only focused on collection, transportation and disposal of waste as stipulated in the Constitution (1996) and the Municipal Systems Act (1998). Due to changing socio-demographic dynamics, they have begun supporting and implementing additional management services that curb the challenges such as long distance travelling to landfill sites and depleting landfill space. **Table 15** shows the number of waste management facilities and strategies currently being implemented in each respective municipality as part of their waste management strategies.

Table 15: Waste Management Services

	CoCTMM	SLM	DLM	CALM	GLM
Landfills	3	1	1	2	2
Transfer Stations	3		1	-	1
Material Recovery Facilities (MRF)	2	1	1	-	-
Public Drop-off sites	25	1	3	3	-
Recycling Programmes	6		-	-	-
Composting		1	-	-	1

Source: IWMPs (2009-2011)

Given the large quantities of waste generated in the City of Cape Town, more municipal solid waste services in CoCTMM are required than in other municipalities in the sample. All the municipalities' landfill sites are currently operational, but most of these sites are almost reaching their full capacity. There are also a number of closed landfill sites that have not been rehabilitated as follows: CoCTMM and DLM have five (5), CALM has four (4), GLM has one (1). This presents a potential opportunity for landfill-gas extraction as part of the rehabilitation process.

Approximately a third of CoCTMM's formal households are serviced by a 'separation at source' collection service where effectively households are asked to separate the waste at their homes. The municipality provides appropriate refuse bags to the areas that receive that service, and residents are required to separate their waste. On collection day residents place the clear bag with the contents on top of the black bin. The bags are collected and moved to a separation facility (MRFs) where that material is further sorted. Kraaifontein MRF, for example, is a facility that caters to this service and serves about 40,000 households (B Coetzee 2015, pers. comm., 24 April).

In the DLM, waste is collected from various towns and hamlets[16] and landfilled in Wellington on a weekly basis. In addition to landfill disposal, eight out of 31 wards in the jurisdiction practice at-source recycling. Other waste management initiatives undertaken in DLM include crushing of builder's rubble and greens' collection at community drop-off centres. The rubble is typically used as backfill in the construction industry, cover material at the landfill sites or in some cases for road construction. The initiatives are not all the same but the practice is to allow residents with larger quantities of recyclable materials to drop them at the designated centres. This allows more waste to be diverted away from the landfill. The municipalities stated that they do not directly participate in composting activities as they are classified as processing and manufacturing, which is not part of a municipality's mandate. This is where partnerships with the private sector are most valuable and prevalent. For example the DLM do have small composting facilities but they mainly sell the compost to the public or private companies (R Brown 2015, pers. comm., 28 April).

Thus, the municipalities are implementing a variety of activities to redirect waste from landfills and adhere to their environmental strategies. Section 78 of the Municipal Systems Act provides a platform for them to identify private sector partnerships that can assist with the processing and manufacturing aspect. Landfilling is still the main method of waste disposal; however, additional activities such as recycling and composting of greens, are also being implemented by the municipalities. A regional landfill site that was proposed 14 years ago is still in a pending court case emanating from the environmental impact assessments around the project.

5.3.3 Budget Increase/Decrease

All municipalities stated that their budgets for solid waste management have increased gradually over the years, some averaging between 6% and 10% growth per annum[17]. This is due to the increasing CAPEX budget which includes services such as landfilling and capping,

[16] A settlement generally smaller than a village.
[17] These expert estimates from the interviews done during the study and it is not clear if they are inflation adjusted figures.

area cleaning and waste minimisation activities. Some municipalities identified fleet operation, maintenance and replacement as some of the major expenses that increased the budget as well as landfill expansions and permit charge increases. Transfer stations and recovery stations also require budgets for labour and technical assistance.

This budget increase is not sufficient for the municipalities to make any investment in waste to energy schemes. Apart from increased waste management costs, the budget has too many competing needs in municipal service delivery and social services. This makes it difficult for municipalities to prioritise waste to energy funding at the expense of more pressing social services. According to one municipality "…*tariff setting and modelling to derive a budget for the city is quite a complex process and because of that you have affordability issues you need to look at when you assume that in the future there will be an addition to the budget as a result of new initiatives*". This essentially captures the challenge that municipalities face with regard to implementing new capital intensive project against tighter budgets and increased poverty levels.

5.3.4 Challenges experienced with current Waste Management methods

The municipalities noted the following as the main challenges they experience with current waste management techniques include decreasing landfill airspace, inconsistent waste generation and composition data and the (increasing) distance between collection and disposal sites as well as public awareness and education. These challenges are discussed in detail below.

1. Decreasing Landfill Airspace

All of the municipalities' current operational landfills have been operating for ten years or more and have a further 12 to 15 years of additional airspace. As indicated earlier, a growing urban population and economy have led to more waste generation. This has resulted in landfills filling at a faster rate – reducing the remaining airspace. Municipalities are then pressurised to find additional land for more landfills or other disposal methods that are cost effective and complement the available waste management strategies. However given the other competing land use demands such as human settlement development, provision of infrastructure amenities and the transition towards sustainable and environmentally benign practices, municipalities need to reconsider landfilling as the primary waste management strategy in the future. There is a need to identify alternative disposal methods that may ease the pressure on landfilling and contribute towards more resource efficiency waste management.

2. Lack of reliable Waste Generation statistics

The respondents all concurred that they do not have up-to-date figures on the quantities and composition of waste generated in their jurisdictions. All five municipalities had weighbridges installed as of 2010, from which more accurate figures could be collected. However, poor recording practices at some landfills affect the consistent data capturing. The respondents also concurred with studies that, in order to identify and implement waste minimisation initiatives, consistent and accurate waste generation and composition figures are required. This data is important for determining the type of intervention that can be applied, where it can be applied, how it can be applied and the financial viability thereof. Without consistent and reliable data, decision making is difficult and this is a major obstacle to initiating new waste management strategies such as WtE. Capturing accurate statistics of waste and its composition is especially important given the demographic dynamics and changes in the economy which affects the volumes and composition of the waste as well as collection efficiency. Although the NWMS (2011) advocates for a national database through a Waste Information System (WIS), the portal does not provide up-to-date information.

3. Distance between Urban areas and Disposal sites

Three of the municipalities indicated that due to expansion of urban settlements, the growing distance between urban areas and disposal sites or waste processing facilities further contributes to the waste management challenge. Given the limited number of landfills and the distance to disposal facilities, this has increased the cost burden on municipalities. The waste collection department needs a vehicle, fuel and maintenance budget. Although some municipalities have transfer stations and MRFs, public-drop off sites and recycling programmes, the growing distance remains one of the key challenges for waste management.

4. Public Awareness and Education

All respondents indicated that the public's limited awareness about and understanding of waste management services impedes on municipalities' ability to effectively and efficiently manage waste. Although the White Paper on Education and Training (1995) advocates for environmental education and training across all government spheres, it is primarily the responsibility of provincial and national government, who then delegate functions to local government. The education and training is not limited to citizens and youth but also includes government officials and workers (policy makers and practitioners) in the local government sphere too (Republic of South Africa, 1995). This is further reiterated in municipalities' IWMPs which also highlight the need and importance of awareness and public participation as encouraged by the Municipal Systems Act of 2000 under Chapter Five.

Despite the aforementioned challenges four municipalities indicated that they have not had any environmental or health issues related to for instance contamination of water bodies due to toxic waste leakage or leaching at landfill sites. In the CoCTMM specifically, the participation of residents' committees as well as ground water and air quality monitoring is done on a regular basis. Hazardous waste is not disposed of by municipalities but by the private sector and this is especially to ensure this type of waste is carefully disposed of without any posing any harm to the environment or residents.

> "While every effort should be made in the first place to minimise generation of waste materials and to recycle and reuse them to the extent feasible, the option of Energy Recovery from Wastes be also duly examined. Wherever feasible, this option should be incorporated in the over-all scheme of Waste Management"
>
> (Ministry of Urban Development-New Delhi, 2000)

5.3.4 Roles and Responsibilities of Local Municipalities

Local municipalities play an important role in addressing the aforementioned challenges. Understanding what their roles and responsibilities are enables citizens, private sector and other organisations to probe for better services, identify and exploit opportunities as well as assess how to curb existing and potential hindrances. Some of the following legislation outlines municipalities' roles and responsibilities in the context of waste-related service delivery:

a) The Constitution of the Republic of South Africa (No. 108 of 1996) – Chapter Seven
b) The Municipal Systems Act (Act 32 of 2000) – Chapter Five
c) White Paper: Policy on Pollution Prevention, Waste Minimisation, Impact Management and Remediation (2000)
d) National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008)

The roles and responsibilities defined in the MSA (2000), the White Paper Policy on PP, WM, IM&R (2000) and NEM:WA (2008) are built on the foundation provided in Chapter Seven of the Constitution (1996), which defines the role of municipal council as follows:

- *Pass by-laws - local laws and regulations about any of the functions they are responsible for. By-laws may not go against any national laws and are subject to the Constitution.*
- *Approve budgets and development plans - every year a municipal budget must be passed that sets down how money will be raised and spent. The Council must also approve the 'integrated development plan'.*
- *Impose rates and other taxes, for example, property tax.*
- *Charge service fees - for using municipal services like water, electricity, libraries, and so on.*
- *Impose fines - for people who break municipal by-laws, for example, traffic fines, littering.*
- *Draw up, approve or amend integrated development plans (IDPs).*

In addition to the above, municipalities are also obliged to use their resources in the interest of the residents in a manner that is accountable as well as to encourage communities to be involved in the service delivery affairs. In terms of Part B of Schedule 4 and part B of Schedule 5 of the Constitution, local municipalities are responsible for the following functions, which all relate to waste management and energy supply:

- *electricity delivery*
- *water for household use*
- *sewage and sanitation*
- *storm water systems*
- *refuse removal*
- *decisions around land use*
- *abattoirs and fresh food markets*

Local municipalities have a responsibility to make laws and decisions that favour the well-being of residents. However, according to Kissoon, et al., (2014), implementing alternative waste treatment technologies may require the introduction of complex policies and regulations and adequate capacity is needed within the municipalities to operationalise these.

5.4 WtE Adoption by Local Municipalities

Objective Two: Investigate local municipalities' efforts to implementing WtE schemes and the challenges they have encountered;

5.4.1 Consideration of WtE's Impact on Energy Demand

In order to understand the rationale for municipalities' to consider WtE schemes as an additional mechanism to address the energy demand and improve existing management methods, municipalities were asked whether they thought WtE schemes would have a significant impact on their jurisdiction's energy demand. One municipality stated "*no, the scale is too small. Many people simplistically presume that you can burn all waste and generate electricity from it*". Using an example of the 50 MW WtE plant in Ethiopia in the Western Cape's context, the energy generated would still not be able to make a significant impact in the province, let alone metro municipalities such as the CoCTMM. This capacity is small compared to CoCTMM's maximum electricity demand level of 1900 MW (CoCT, 2015[18]).

Generally, municipalities agreed that WtE technologies are favourable from an environmental perspective (addressing carbon emission reduction and waste minimisation) but not in terms of addressing energy supply shortfalls. But the respondents agreed that despite the limited potential of energy from waste in the region, small embedded generators can play an important role in contributing to the total energy supply both locally and nationally. They also emphasised that energy production should be considered as a by-product of an integrated waste management strategy rather than as the primary (stand-alone) activity if WtE is to financially viable. From a comparative capital investment perspective, the respondents consider gas and heat energy production to be more attractive financially than electricity generation or using transport applications, given that the latter are capital intensive.

Nonetheless, most municipalities acknowledged the following benefits that can be derived from WtE schemes – for example energy by-products, reducing the pressure on land and landfilling, diversion of organic waste which would also contribute towards reducing carbon emissions from landfills. However a detailed cost and benefit analysis has to be conducted so as to assess the viability of specific WtE projects. Thus WtE is considered more as part of an

[18]COCT. 2015. City of Cape Town Cape Town STATE OF ENERGY 2015. Available at: https://www.capetown.gov.za/en/EnvironmentalResourceManagement/publications/Documents/State_of_Energy_Report_2015_2015-09.pdf

integrated waste management strategy rather than a significant energy production undertaking which can make a significant impact of the energy supply.

5.4.2 Existing and (or) Proposed WtE Adoption

There are very few municipal driven WtE projects in South Africa, none of which are fully operational projects in the Western Cape. One municipality stated that as a country and specifically municipalities, "*we are not keen on exploring other avenues but now we are talking about Mechanical Biological Treatments (MBTs) and other international terminology*". This can be interpreted as a signal of reluctant embracement of new techniques in order to be able to deal with new forms of challenges. It shows that WtE is a concept that municipalities in the Western Cape are starting to talk about but they are generally waiting to see what is being done by others or see working cases before they can make decisions on the technology. Thus, few municipalities in the province are yet to conceptualise and consider adopting these technologies. **Table 16** illustrates the local municipalities that are considering WtE schemes:

Table 16: WtE Activities in the Western Cape

Municipality	Stage of WtE	Status of WtE	Technology	(Proposed) MW Capacity
CoCTMM	Feasibility Study	Submitted to Council	Landfill GtE	2MW
SLM	Feasibility Study	In progress*	Landfill GtE	1.6MW
DLM	Feasibility Study	EIA Process	Landfill GtE	10MW
CALM	Feasibility Study	In progress*	AD (WWTW)	4.4MW
GLM	PPA	Awaiting operation	Incineration	5MW

* Note: In progress means the WtE feasibility study is currently being undertaken

There are currently no operational WtE facilities in any of the sampled municipalities. Four of the municipalities are at the feasibility study stage and the other has already reached a power purchase agreement (PPA). Generally, WtE activities are implemented by the private sector[19] who either operate their own facilities (capitalising on waste heat from industrial and commercial activities) or implement these on behalf of private clients and communities.

[19] Examples include: Anaergia (Pty) Ltd, Bio2Watt (Pty) Ltd and Agama (Pty) Ltd.

The CoCTMM is currently conducting feasibility studies to determine the potential of harnessing energy from waste in accordance with the Municipal Systems Act section 78(3). The metropolitan municipality has plans to implement landfill gas projects at three of their landfills, which will be linked to the Clean Development Mechanism (CDM). According to the CoCTMM, new AD projects have been proposed but these have not yet taken off. One of the proposed WtE projects is the implementation of a mechanical biological treatment (MBT) facility at the Athlone Refuse Transfer Station (ARTS). However, whether the full MBT route will be implemented is still to be determined because the biological treatment may not be accommodated due to land limitation at the ARTS. This project is also expected to be linked to the Visserhok landfill. Two other WtE feasibility studies are being conducted by the CoCTMM for the Coastal Park landfill (which will be purely electricity generation for 2MW) and the Bellville South landfill site, which will focus on industrial heating. Another project includes a pyrolysis WtE pilot project that is being funded by the Japanese government, which is expected to be implemented this year. The proposed pilot project will be processing approximately 500kg of plastic feedstock over a six month period to produce 500 litres of heating oil that will be used as feedstock for a generator at the Kraaifontein facility. The municipality indicated that "*at the end of that term there will be an evaluation of the technology and performance and output and quality of output. That evaluation will become the basis on which to make decisions whether to continue with that as a technology or not*".

CALM conducted a WtE feasibility study in 2010 which focused on energy from the Waste-water Treatment Works (WWTW) in the main town of Bredasdorp. The project would comprise of firstly, a waste treatment plant (3 million litres per day) which includes waste separation and water treatment facility; secondly an AD facility; thirdly a methane gas treatment and combined heat and power (CHP) generators; fourthly feedstock storage facilities for one week supply for bio-digesters; and lastly, storage facilities to handle by-products (Ark Industries, 2010). In addition to the waste water, the bio-digester feedstock also comprised of: abattoir waste, green pruning, cattle manure, poultry litter and pig abattoir waste, therefore increasing the calorific value. The outputs of the facility include electricity, heat and digestate. It is not clear as to whether the facility is functional yet. CALM and the project developers could not provide further details. Access to information was noted as a limitation earlier in this study.

Before considering WtE as an alternate method of disposal, DLM deliberated over the idea of taking their waste for disposal to Vissershok, in Cape Town. However the transport costs were projected to R5 million per month – excluding dumping fees. This encouraged the solid waste department and other officials to consider alternative waste management methods such as

WtE. The municipality entered into a PPP with a service provider for the next 20 years. The funding model is that *"they build the infrastructure with their funding and we'll buy the electricity from them and we pay for the gate fees*"(R Brown 2015, pers. comm., 28 April). After two years the Build, Operate and Transfer (BOT) system will be implemented and the site transferred to the municipality after 20 years.

In SLM, the WtE project is still at the conceptual design stage as it requires careful planning. The project presents two big opportunities namely: landfill gas extraction and brick making from construction waste. The landfill site was poorly managed in the past and the compaction was not good, which led to the development of slopes within the landfill (impacting the quantity of gas attainable). The municipality is currently conducting a pre-feasibility study to determine whether a WtE scheme would be suitable and if so, the most appropriate technology as well as socio-economic impacts. The findings are expected towards the latter part of 2015.

Interestingly, both the SLM pre-feasibility study and DLM feasibility study are still to determine whether it would be a better option to mobilise for a regional integrated waste management facility – preferably the Kraaifontein Integrated Waste Management facility - that includes technologies such as AD, incineration and MBT. Both municipalities are also considering capitalising on WWTW by either linking them to the proposed WtE schemes or simply adding anaerobic digesters. Where waste operations are in close proximity, the objective will be to try and have an anaerobic digester. In the case of DLM there is an existing AD in Paarl, thus additional sludge from Wellington will be transported to that facility and the energy generated will be used to operate the entire Paarl WWTW.

The GLM adopted a WtE scheme that will rely on wood-bark, wood chips and saw dust - to generate electricity for the jurisdiction. The project is not led by the municipality but by the Central Energy Fund (CEF). Electricity will be generated in George municipal area and purchased by Eskom and no municipal funds are allocated for the project. The electricity will be wheeled through the municipal network. The project is still to be implemented because the date of commencement has not been determined due to legislative and policy barriers. The plant has an expected generation capacity of 5MW of base load electricity and it is valued at R200 million (K Grunewald 2015, pers.comm, 10 July).

5.4.3. Challenges encountered attempting to implement WtE schemes

Below is the core component of this research: a discussion of the factors impeding local municipalities from adopting WtE technologies. Of the four municipalities with WtE projects currently at feasibility study stage, three municipalities noted a number of challenges and concerns that partially motivated the need to conduct feasibility studies. The majority of challenges identified coincide with those noted by van der Merwe (2014) which include: "low gate fees at landfills (thereby still making it attractive), complexity of waste supply, relatively low electricity prices, high capital costs of most WtE facilities, public perception of WtE, lengthy EIA and governmental approval processes, initiating electricity agreements with municipalities (Regulated by Municipal Finance Management Act and Municipal Systems Act), time consuming carbon financing registration processes, skills shortages and lack of research and development"(van der Merwe, 2014, p. 12).

<u>1. Unsuitable Waste Feedstock and Poor Data on Waste Generation and Composition</u>

The respondents indicated that their different waste streams not only had an impact on the type and quantity of energy that could be generated but whether existing activities such as composting and recycling would have to be stopped or reduced. Some WtE technologies such as anaerobic digesters, incinerators and pyrolysis require a sustainable supply of a specific type of waste steams like organic material and plastics. The type of waste also affects the performance of the WtE technology and the waste may require separation or sorting before it is used for specific conversion technologies. Contamination may affect the energy production potential and these issues need to be considered especially when large capital investments are made.

Furthermore the availability of waste data and statistics on platforms such as the South African Waste Information Centre (SAWIC) is very poor (Van der Merwe (2014). SLM landfill has a weighbridge to assist with quantification as this has an impact on viability of adopting WtE. Sufficient and sustainable feedstock determines whether an energy plant will be viable or not. DLM indicated that their feedstock requirements would be 500 tonnes of waste per day for a 10MW plant but they currently generate 300 tonnes only, meaning 200 tonnes would need to be brought in from elsewhere which poses an additional cost of transportation. Although municipalities are not research and development institutions, it is imperative that they remain well-informed regarding new developments in waste management (Sebola, et al., 2014; Munganga, 2014).

2. Bureaucracy pertaining to Electricity Supply and Poor Synchronisation of Policies

According to the respondents, for private projects, municipalities are not permitted to purchase electricity from independent power producers apart from Eskom; only Eskom can purchase electricity from renewable energy power producers[20]. Obviously this only affects those municipalities that want to purchase power from IPPs in long term contracts. This was one of the biggest challenges faced by GLM when they intended to purchase electricity directly from the producer. This is because the project was not regarded as a municipal project but a project of the parastatal CEF. Additional challenges pertain to bureaucratic processes that delayed the project and the operation date is still unclear. A similar challenge was encountered by the eThekwini Municipality regarding implementation of renewable energy projects, particularly the landfill gas to energy projects.

The Electricity Regulations on New Generation Capacity of 2009 (updated 2011), focuses on small-scale power generation and embedded generation. In 2011 the National Energy Regulator of South Africa (NERSA) approved standard conditions for small-scale embedded generation within municipalities' boundaries (less than 100kW) meaning municipalities played a key role in local power generation (Department of Energy, 2011). However, this is not possible because of the current legislative framework which in essence states that "Municipalities are not able to license embedded generators, as NERSA is currently the only body that is able to issue such licenses, and contracts for PPAs are limited to a three year period, based on a 2011 council resolution" (Energy Office - eThekwini Municipality, 2013).

There is a complex legal process which some municipalities such as eThekwini have tried to follow to get permission to buy power from an IPP. According to eThekwini Municipality (2013), the municipality got legal advice that the existing by-laws could be amended to allow municipalities to enter into 20 year PPAs or consider licensing embedded generators themselves, but the processes are not that simple.

Poor synchronisation of legislative frameworks such as the Municipal Finance Management Act 56 of 2003 (MFMA), the Electricity Regulation Act 4 of 2006 (ERC), Section 84 of the Municipal Structures Act 117 of 1998 (MSA) and Preferential Procurement Policy Framework Act (Act 5 of 2000) regarding electricity supply, contract periods and application processes, is a major hindrance. Implementing long term PPAs between municipalities, small-scale power

[20] As an example of this problem, eThekwini Municipality has been exploring legal routes to enable them to purchase power directly from IPPs. This should not be a problem if the municipality is generating power for its own consumption.

producers or embedded generators becomes a lengthy, costly and complex process (Energy Office - eThekwini Municipality, 2013; Mannie & Bowers, 2014). This is further hindered by wheeling fees which are required for transmission and distribution (J Palm 2015. pers.comm, 11 August; Tiepelt, 2015).

3. Poor Integration of WtE into Waste Management Planning

With regard to waste management related policies, two major policies provide a platform from which municipalities address waste. These are the National Environmental Management: Waste Act (NEM: WA, Act 59 of 2008) and the National Waste Management Strategy (NWMS, 2011). The NWMS is a legislative requirement of the NEM: WA which aims to achieve the following goals:

- Promote waste minimisation, re-use, recycling and recovery of waste
- Ensure effective and efficient delivery of waste services
- Grow the contribution of the waste sector to the green economy
- Ensure that people are aware of the impact of waste on their health, well-being and the environment
- Achieve integrated waste management planning
- Ensure sound budgeting and financial management for waste services
- Provide measures to remediate contaminated land.
- Establish effective compliance with and enforcement of the Waste Act.

Both policies require municipalities to consider alternative waste management technologies in their current management systems. In order to accomplish integrated waste management, a number of technical and non-technical decisions are required at various government and stakeholder levels. These decisions contribute towards the development of an Integrated Development Plan (IDP) which informs and guides municipalities' operations and developmental priorities. According to the Municipal Systems Act (MSA, Act 32 of 2000) municipalities are required to adopt a five year strategic and developmental plan which:

a) links, integrates and co-ordinates plans and takes into account proposals for the development of the municipality;
b) aligns the resources and capacity of the municipality with the implementation of the plan;
c) forms the policy framework and general basis for annual budgets; and
d) is compatible with national and provincial development plans and planning requirements binding on the municipality in terms of legislation.

Table 17 shows that the sampled municipalities have all implemented IWMPs and IDPs which could support waste to energy initiatives.

Table 17: Municipalities' Policy Frameworks

	IWMP	Year	IDP	Period	Mention Alternative Technologies
CoCTMM	Yes	2006	Yes	2012-2017	Yes
SLM	Yes	2010	Yes	2012-2017	Yes
DLM	Yes	2009	Yes	2013-2018	Yes
CALM	Yes	2011	Yes	2012-2017	No
GLM	Yes	2014	Yes	2012-2017	Yes

Upon evaluation of the linkages and alignments between the municipalities' IWMPs and IDPs, it was evident that the alignments were weak and there was limited inclusion or consideration of WtE schemes. The plans allude to adoption of alternative technologies but without explicit reference to the types of technologies or WtE in particular. Sango et al (2014) concur with this finding by stating that the IWMPs need to be more aligned with the IDP in order to implement waste management initiatives. Without policy recognition and support, mobilising WtE schemes becomes a little more difficult to implement. The authors go on to emphasise that although municipalities in the Western Cape have drafted 2nd generation IWMPs "there is still a big gap with regards to future planning and integrated waste management as a whole, and alignment of the IWMP with local, provincial and national strategies and plans" (Sango, et al., 2014, p. 224).

Two main challenges are evident from the above: firstly, municipalities need to better align both IWMPs and IDPs to address current waste management initiatives. Secondly, the fact that WtE technologies are not discussed or included in either plans as alternative management techniques implies that they do not have regulatory support yet, thus potentially reducing their chances of adoption. This may be attributed to the NEM: WA objectives which encourage (1) waste avoidance, (2) waste reduction and (3) waste disposal but do not mention WtE technologies.

4. Limited Knowledge of Technologies by Decision-makers and Political Will

The respondents stated that not all decision makers are well versed with the concept of WtE: in terms of the relevant technologies, their implementation and benefits. The respondents identified a number of technological challenges that decision makers have encountered, which are associated with adopting WtE technologies. Firstly the lack of technical understanding of the basics well as advanced technologies is a significant impediment to the promotion of these technologies. An appreciation of the technologies would be useful in developing of appropriate regulatory framework and creation of appropriate conditions for the deployment of the technologies. These challenges are further exacerbated by lack of support structures such as the lack of material handling and sorting systems. This means most of the waste is not completely valorised. Furthermore limited skills of plant operators and maintenance problems with some complex systems and equipment may lead to challenges in the operation and maintenance of the technologies (Greben & Oelofse, 2009; Mannie & Bowers, 2014).

In addition political will and limited knowledge about WtE technologies amongst decision makers in municipalities impacts (1) whether a technology is considered and if so (2) to what extent and (3) whether it is the most appropriate. This is also dependent on the category of municipalities. Presently municipalities are categorised as follows – see **Table 18**:

Table 18: Categorisation of Local Municipalities

Municipal category	Definition
A	Metropolitan
B1	Secondary City
B2	Local municipality with a large town as an urban core
B3	Local municipality with a small town or towns as an urban core
B4	Local municipality with no urban core
C1	District municipality which is not a Water Service Authority
C2	District municipality which is a Water Service Authority

(The Local Government Handbook, 2015)

The purpose of the classifications is to show the differences in the types of settlements and institutional formations between the municipalities so as to better understand the service delivery issues. One municipality stated that the bigger municipalities have better political leadership through the Mayors and Mayoral Committees who are able to champion initiatives that show innovation, sustainability and better service delivery. However, a challenge arises when the political leadership is not well informed about these technologies and at times fail to appreciate and distinguish problems from solutions. The WtE industry in South Africa is still small and underdeveloped and one tends to come across "*snake oil salesmen*" who overwhelm the decision makers with information about how great and effective a specific technology is and how it could change the municipality. In some instances, decision makers embrace the technologies without adequate information and detailed feasibility studies. This potentially leads to many problems before the project even begins, which discourage the decision makers from re-considering it in future. Thus, a poor understanding particularly by decision makers leads to indecision by municipalities and refrain from adopting WtE schemes. There is no 'one size fits all' when it comes to WtE technologies, many factors influence the decision and this further emphasises the need for more feasibility studies and a better understanding.

5. Low Landfill Tariffs

Three municipalities stated that they have never taken WtE schemes seriously mainly due to the low costs of landfilling and it is still considered simple technology to implement.If implemented purely for energy production and not as part of an integrated waste management strategy, iimplementing WtE technologies is still considered more expensive than other renewable energy technologies such as wind and solar technologies, thus there is no motivation to generate energy from waste when there are cheaper technologies. Also WtE technologies are still considered to be novel and 'unfamiliar', thus carry some underlying risk. In the past, municipalities attempted to explore WtE options by developing proposals to explore the feasibility but most ideas have been considered unattractive. Reasons for this included: poor evidence of plants which successfully operated between three and five years, the proposals were not financially viable and the projects therefore were deemed unsustainable (Haider, 2012).

It is also known that the landfill life spans are gradually reducing, but the laws of supply and demand do not appear to have an impact on landfilling. Some landfill tariffs still operate at R150 per tonne, which to some extent encourages landfilling and attract waste from surrounding areas. One municipality stated that "*you can't have landfills operating at R150 and that's your entry for waste-to-energy, how are you going to justify moving? You got to start pushing that up because that is right down in your hierarchy, why is it so cheap?*" The shorter the landfill lifespan the more uneconomical it becomes (S Haier 2015, pers.comm, 2 May; van der Merwe, 2014).

6. Capital to Invest in Waste to Energy Technologies

The sampled five municipalities identified capital investment as a major challenge to establishing WtE facilities. Unlike developed countries like the UK, Sweden and Japan whose governments are able to fund 50% of large scale and capital intensive renewable energy projects (B Coetzee 2015, pers. comm., 24 April), municipalities in developing countries such as South Africa must explore ways to fund their projects, typically through public-private-partnerships for capital intensive projects. Below (in **Table 19**) are examples of average investment and operational costs for WtE technologies in Europe:

Table 19: General Cost of Waste Treatment Technologies in Europe[21]

Mechanical Biological Treatment (general)				
Capacity (t/yr.)	Investment		Operational Cost	
	(million €)	Rands (million R)[22]	(€/t)	R/t
25,000	12,2	169	24-81	334-1,128
60,000	13,5	188	24-81	334-1,128
100,000	56	780	-	
Anaerobic Digestion (alone or in MBT)				
Capacity (t)	Investment (million €)	Rands (million R)	Operational Cost (€/t)	R/t
40,000	6,2	86	39,1	544
100,000	7,5-18	104-250	21	292
Incineration				
Capacity (t)	Investment (million €)	Rands (million R)	Operational Cost (€/t)	R/t
33,000	34-39	473-543	191-205	2,660-2,855
50,000	20-30	278-417	-	

[21] http://www.epem.gr/waste-c-control/database/html/costdata-00.htm
[22] 1 Euro equals 13.93 South African Rand – 3 August 2015

Table 20: Comparison of Biomass Conversion and WtE technology Costs

	O'Connor, 2011	**Mott MacDonald, 2011**	**EPA, 2007 and EIA, 2010**	**Obernberger, 2008**
		(2010 USD/kW)		
Stoker boiler	2,600-3,000	1,980-2,590	1,390-1,600	2,080
Stoker CHP	2,500-4,000		3,320-5,080	3,019
CFB	2,600-3,000	1,440	1,750-1,960	
CFB CHP			4,260-15,500	
BFB		2,540	3,860	
Co-firing	100-600			
100% biomass repowering	900-1,500			
MSW	5,000-6,000			
Fixed bed gasifier ICE		4,150	1,730	4,321-5,074
Fixed bed gasifier GT	3,000-3,500			
Fluidised gasifier GT			2,470-4,610	
BIGCC	3,500-4,300		2,200-7,894	
Digester ICE	1,650-1,850	2,840-3,665		
Digester	1,850-2,300			
Landfill gas ICE	1,350-1,500		1,804	

Key: ICE – international combustion engine; GT - gas turbine; CFB - circulating fluidized bed gasification; BIGCC– Biomass integrated gasification combined cycle

Source: IRENA (2012).

It is evident from **Table 19** and **Table 20** above that WtE technologies require high investment capital (at 1200-7700 $/kW) compared to say coal thermal power plants (600-3700 $/kW) or combined cycle gas turbine (760-1500 $/kW).These costs are dependent on the scale, small plants (below 10MW) cost around 5$/kW while larger plants can drop as low as $1500/kW. In comparison, the investment cost for other renewable energies such as solar plants (1100-6200 $/kW), wind power (1100-6000 $/kW) (WEC, 2013), WtE are competitive – depending on scale and context, although the bankability is difficult to determine given risks (explained below). However, if the WtE plants are considered as part of a broader waste management strategy, then the investment appraisal and cost benefit analysis would consider other socio-economic and environmental benefits which are not typically internalised in basic financial appraisal analysis. This is beyond the scope of the current analysis and is recommended for further study. Also WtE technologies must be compared to fossil technologies and not only other renewables, given that the resource is readily available. Overall, the above data supports the assertion by municipalities that WtE technologies require significant amounts of capital to establish and given the tight budgetary environment and many competing social needs on their agenda, municipalities can hardly afford to invest in WtE schemes.

Three municipalities stated that South African local municipalities have limited budgets which are prioritised for more pressing issues such as housing and sanitation. If a feasibility study indicates that there is potential to generate sustainable energy it does not necessarily guarantee that the required financing will be provided – even in situations where PPPs are implemented. As indicated in above, investors such as commercial banks and private developers want to assess how ‘bankable’ the project is before providing the capital. Due to the nature of WtE industries in South Africa, there are high risks involved with financing such projects. These risks relate to the fluid nature of waste as a feedstock resource, the exact composition and characteristics can only be determined when delivered. If a batch of waste is delivered with contamination, or if waste volumes collected fluctuate – all this can affect the rated plant capacity, energy production and investment returns. Where waste feedstock is expected to be dry, the moisture content may increase in the wet season and this will affect the energy balance and profitability of the operations. Waste is not a homogeneous fuel and that’s presents challenges to expectations on delivery and investors are naturally worried about the implications. Additional economic indicators to consider include capital cost, operating cost, electricity price, heat price, digestate sales income and tipping fee income (Greben & Oelofse, 2009)

Generally, residents of municipalities tend to bear the financial burden in any municipal project, either through increased rates or some sort of monthly service fee. Thus the challenge as municipalities is to develop a technology that is affordable in all regards. These are the issues that the feasibility studies and technical advisers will be able to assist in each municipality. It is useful to demonstrate that the technology works through pilot or demonstration plants of WtE technologies. However, establishing such pilot plants also require resources and expertise which may not be available. Furthermore, Section 78 of the MSA (2000) explains that high-tech investments are not feasible for municipalities. Instead, they should focus on low tech activities such as encouraging composting and recycling activities.

Table 21 outlines the estimated technology investments for the different municipalities as provided by the interviewees. The generation capacities for CoCTMM and GLM are between 2MW and 5MW and cost R50-200 million while DLM's proposed technology is expected to generate 10MW and cost R34-300 million. Given that municipalities are mandated to deliver other services to residents, some of which may be considered of higher priority than WtE, the concerns regarding project payment arise.

Table 21: Estimated Technology Investment

	CoCTMM	SLM	DLM	CALM	GLM
Proposed Capacity (MW)	2	1.6	10	4.4	5
Investment (million R)[23]	50		34-300		200

(B Coetzee 2015, pers. comm., 24 April; R Brown 2015, pers. comm., 28 April; K Grunewald 2015, pers.comm, 10 July)

7. Lack of technical Skills

Lack of operational and maintenance skills to operate WtE technologies were noted as both a challenge and a risk. Although technologies such as anaerobic digestion, incineration, and pyrolysis are argued to be relatively mature, South Africa does not have sufficient skills to ensure sustainable operations (B Coetzee 2015, pers. comm., 24 April). There are aspects of the technology that are complex and require highly skilled personnel. Municipalities are unlikely to operate such facilities and so private operators have to be brought in and that may entail additional costs (if one considers that municipalities are public bodies which are not driven by profit motives). On the other hand, private operators may be more efficient and lower production costs. Mannie & Bowers (2014, p. 429) concurred with this by stating that "due to the scarce skills in waste management in the country and particularly at municipal level, you will often find inappropriate persons taking charge of the waste department or leading the waste programme" which impedes on implementation of favourable waste solutions.

[23]The investment figures were obtained from the interviews conducted. They are estimated because the respondents' feasibility studies and policy frameworks were not publicly available until internal protocols were completed. These are expected in the latter part of 2015/early 2016.

8. Limited Awareness and Opposition from Public

During their feasibility study, DLM experienced opposition from the public who voiced concern about the potential for smells and pollution[24] emanating from the proposed WtE facility among other negative perceptions. Other respondents also concurred with this challenge. There was 'public outcry' on various social media platforms protesting against the establishment of WtE facilities. According to one respondent, three rounds of public participation were held so as to educate the public while encouraging them to be involved throughout the different implementation stages. Major concerns surrounding WtE – particularly thermal technologies such as incineration - are environmental and health related for example the release of hazardous gases and by-products like ash.

9. Delays in Processing Environmental and Legal Applications

Existing environmental and legal requirements make it difficult to adopt WtE schemes. Two of the respondents indicated that the Municipal Financial Management Act & Municipal System Act (Section 78) makes it difficult to procure long term agreements for WtE projects and for municipalities to enter into PPPs. Further challenges that were noted include restrictive environmental regulations contained in the National Environment Management Act (NEMA) resulting in delays in issuing environmental authorisations and licences, procurement processes within municipalities, opposition from environmental and citizen groups as well as land ownership and zoning (Mthembu, 2012). Another respondent pointed out that it has been difficult to convince environmental regulatory authorities to establish landfill to energy schemes as they have stringent requirements on leachate into groundwater.

[24]Incineration plants need to put in place scrubbing devices to deal with potential toxic fumes that result from the combustion of the different kinds of toxic material that constitute MSW. Some residents may also simply be opposed to the idea of any kind of fumes/emissions in their neighbourhood. According to the World Bank (1999), in terms of odour only, *"…the combustion process destroys all odour-emitting substances in the waste, and the slag and fly ash are sterile and odourless after cooling. MSW incineration plant odour is thus emitted mainly from handling and storing waste before combustion.….. Some of the waste may be in the pit for several days before being fed to the furnace. In this period, the putrescible waste will degrade under anaerobic conditions—especially at high ambient temperatures—and emit an unpleasant smell. The necessary handling of the waste in and around the pit will create odour—and will make bacteria and toxins airborne……"*

5.5 Potential Energy Production from Current Waste

Objective Three: Estimate the amount of energy that can be produced by local municipalities from waste and the extent to which the energy gap could be narrowed;

Objective Four: Identify the most appropriate waste-to-energy technology that can be deployed by local municipalities.

5.5.1 Existing Energy Demand and Supply

Municipalities obtain their electricity supplies primarily from Eskom for distribution within their jurisdictions, but due national electricity supply shortfalls, extensive load shedding has had to be effected to manage the supply and demand fluctuations – this is discussed in detail in the Chapter 2. **Table 22** illustrates the electricity demand, sales and losses[25] for the sampled municipalities. These supply and demand statistics in the selected municipalities are important to consider given the potential energy generation from waste estimated below. This allows us to assess the potential impact of waste to energy supply against current electricity demand and supplies.

Table 22: Annual municipal Electricity Demand and Supply, 2014 - 2015

	Demand: Purchased (GWh)	Supply: Sold (GWh)	Losses(GWh)	Percent Lost (%)
CoCTMM	10,256	9,302	955	9
SLM	390	356	34	9
DLM	722	668	54	7
CALM	70	63	7	10
GLM	449	422	28	6

Source: The GreenCape (2015)

[25]Electricity losses comprise of technical and non-technical losses. Technical losses refer to resistive losses in the distribution network (so-called I^2R losses), while non-technical losses include theft of electricity through by-passing of meters and unmetered consumption.

As shown in **Table 23**, the electricity supply to City of Cape Town includes about 450 GWh of 'local government' demand and this is assumed to include "own use" by the municipality. Thus the statistics on municipal electricity supply (given in **Table 22**) include a substantial proportion of own electricity demand.

Table 23: Electricity balance, Cape Town (2012)

Electricity supply/sector	Electricity amount (MWh)
Electricity: national transmission grid	12,990,012
Electricity: independent power producers (CCT power purchase agreement)	7,770
Electricity: small-scale embedded generation	195
Total supply	12,997,977
Total final consumption	11,944,637
Residential	4,464,862
Commerce and public services	5,267,913
Industry sector	1,551,114
Transport sector	-
Local government	449,478
Agriculture	211,270
Losses	1,053, 340
% losses	8%

Note: Electricity losses included for municipal distribution only

Source (CoCT, 2015)[26]

5.5.2 Energy Production Potential

Potential energy production from waste is estimated using the methodology described in Section 4.5. There are two main waste to energy conversion routes which have been considered in this study: thermo-chemical conversion via incineration of MSW and bio-chemical conversion of organic biodegradable waste via anaerobic digestion. An estimate was

[26]COCT. 2015. City of Cape Town Cape Town STATE OF ENERGY 2015. Available at: https://www.capetown.gov.za/en/EnvironmentalResourceManagement/publications/Documents/State_of_Energy_Report_2015_2015-09.pdf

made for each selected municipality depending on the type of waste generated. The energy potential estimates results are given in **Table 24**[27] and **Table 25**.

Biological Conversion

With regards to organic waste material to energy conversion, CoCTMM has potential to generate about 165 million m^3 of biogas per annum compared to about 3.2 and 2.7 million $m^3$for SLM and DLM, on the basis of assumptions made in this study. The larger biogas potential is attributed to the larger volumes of organic waste that are generated in the larger CoCTMM. We assume the efficiencies of the facilities in all municipalities are the same. In reality, the larger plants may have better efficiency and thus the AD systems for bigger municipalities are expected to perform better than in the smaller municipalities. There is no data on the organic fraction of waste in the other two municipalities, thus, we were unable to estimate the biogas potential. If the biogas is converted to electricity via simple steam turbine technologies with modest efficiency of 30%, the CoCTMM has potential to generate about 296 GWh of electricity compared to 6 and 5 GWh for SLM and DLM.

Table 24: Energy Recovery Potential for the Different LM via AD per annum

Municipality	**Estimated Energy Recovery potential**		
	$10^6 m^3$ of biogas	**TJ of energy**	**GWh of electricity**
CoCTMM	165	3,547	296
SLM	3.2	69	5.8
DLM	2.7	57	4.8
CALM	-	-	-
GLM	-	-	-

Thermo-chemical Conversion

Table 25 shows the estimated electricity production from combustible waste in the sampled municipalities (mainly paper and plastic waste). CoCTMM has potential to generate about 1,476 GWh of electricity from waste. Of the smaller municipalities, DLM has potential to generate 45 GWh of electricity while SLM and GLM can generate 23 GWh and 28 GWh respectively. CALM can only generate 2 GWh.

[27] There is uncertainty on waste generation figures and composition and these need to be up-dated. This is one of the key challenges affecting waste to energy decision making.

Table 25: Electricity production potential from MSW in selected municipalities

Municipality	Electricity generation potential (GWh)
SLM	23.2
DLM	44.7
CALM	2.1
GLM	27.9
CoCTMM	1,476

For both WtE technologies, population size and waste quantities influence the amount of energy recoverable in the municipalities, as well as economic activities. For example SLM's organic material is able to recover more energy (3.2 million m^3) than DLM due to the structure of economic activities; SLM is more agricultural-based than DLM.

5.5.3 Assessment of impact of WtE potential on the energy gap

As alluded to earlier, electricity supply shortfalls and associated load shedding negatively impact on economic activities and human welfare in the country. This challenge facing the country is worsened by challenges such as aging electricity generation plants and increasing demand. **Table 26** gives a comparison of the current electricity demand in each municipality and the potential electricity production from WtE activities (in this case combined incineration and AD potential).

Table 26: Comparison of Municipal electricity demand and potential supply from WtE schemes

Municipality	WtE technology	Electricity production by technology (GWh)	Total Electricity generation potential (GWh)	Electricity Demand (GWh)	% of Demand Met by electricity from waste
SLM	AD	5.8	29.0	390.2	7%
	Incineration	23.2			
DLM	Organics	4.8	49.5	722	7%
	Incineration	44.7			

Municipality	WtE technology	Electricity production by technology (GWh)	Total Electricity generation potential (GWh)	Electricity Demand (GWh)	% of Demand Met by electricity from waste
CALM	Organics	-	2.1	70	3%
	Incineration	2.1			
GLM	Organics	-	27.9	449.5	6%
	Incineration	27.9			
CoCTMM	Organics	279.7	1,772	10,256	17%
	Incineration	1,476			

When electricity potential from AD and incineration are combined, CoCTMM would produce almost 1,800 GWh per annum from WtE technologies. This followed by DLM (about 50GWh), SLM (about 29GWh) and GLM (about 28 GWh). For most of the municipalities, waste to energy has potential to substitute only less than 10% of the current electricity demand, implying that WtE could play a minor role in energy supply but contribute to the growing alternative energy supply base for the country.

In the case of CoCTMM, WtE could contribute about 17% of the electricity demand which is significant considering the potential to offset load shedding in the city and contribute to both cleaner production and waste management. Given that waste to energy has potential to cover 3% to 17% of electricity demand in the selected municipalities, implementing WtE schemes in the sample municipalities can contribute significantly to addressing the electricity shortfalls in the province – on condition that the WtE schemes are economically viable and adequate waste feedstock can be mobilised for the WtE facilities. This takes into account the fact that part of the waste such as plastic and paper will continue to be processed through the current recycling channels.

Thus, WtE can contribute to both energy supply and also as an alternative method of managing waste and curbing carbon emissions. Depending on various factors (and assumptions used in this analysis), WtE has the potential to contribute towards improving the energy supply for municipalities. It is important, however to conduct further research to determine for validity of the key factors affecting the potential energy generation such as calorific value of waste, as well as conduct the necessary feasibility studies to assess viability.

The WtE facilities can contribute to the so-called small scale embedded generators which, in spite of small capacities in some instances can still play a significant role in stabilising the local network and firming the power in the municipalities. It could be (for instance) a 10% supply from a WtE plant could provide enough electricity to avoid load shedding in a municipality depending on power allocation during such crisis periods. It should be emphasised that WtE schemes have to be seen as an additional waste management method, one that cuts into the energy sector. Thus WtE should not be seen as a method to replace recycling and composting activities, for instance.

A thorough economic analysis has not been done in this study to assess the economic viability of WtE schemes. This additional analysis would inform the municipality on the economic sustainability of WtE technologies. However, on the basis of mature WtE technologies and experiences from other countries, it can be inferred that WtE can potentially be economic if various externalities are taken into account and WtE is integrated into waste management.

5.5.4 Proposed WtE Technologies

Municipalities were asked which WtE technologies they considered suitable for adoption within the Western Cape as well as in South Africa. Two technologies that were deemed most suitable in terms of their relative simplicity and commercial experience are AD and incineration[28]. With the right type of feedstock, consideration of environmentally benign designs and conducive parameters, clean energy can be produced using these technologies. Four municipalities mentioned AD (including landfill gas extraction) and incineration because both technologies are "mature" and there is significant experience globally in applying the technologies using waste as feedstock. Other technologies such as gasification of waste are not commercialised yet and applied widely globally, and thus considered risky. Pyrolysis was identified as a technology worth further exploration, because there is a pilot project in the province and this has raised awareness on the technology. The respondents were also cautious about the feasibility of pyrolysis and await results of CoCTMM's pilot pyrolysis project set for the latter part of 2015. The technology choices of the municipalities are motivated by the knowledge of the composition of waste in each municipality, cost and skills/capacity implications and maturity of the technologies.

[28]These two technologies are "relatively" simple to establish and operate compared to gasification and pyrolysis. However, depending on the needs and applications, AD and incineration facilities can have additional features such as gas upgrading to meet different applications needs.

The main factors that determine the type of technology that can be adopted and the energy output include: the waste quantity and composition, inert materials, the calorific value and moisture content (Amber, et al., 2012; Fobil, et al., 2005; Grubler, et al., 2012; Ministry of Urban Development-New Delhi, 2000) – See **Table 27**. Thus the technology selection should consider these threshold guidelines to ensure the technology is feasible within a given context.

Gasification and Pyrolysis are also important technologies but more experienced and learning is required for application in the South African context. The technologies are more advanced and require more capital investment as well as O&M skills set and thus not as competitive as AD and incineration. Literature further supports these results as Munganga (2014) and Oliviera de Medeiros (2012) stated that developing countries tend to adopt AD and incineration due to their simplicity and cost-effectiveness. However, more research is required to establish the feasibility of these more advanced technologies so that the region can take advantage of them.

According to the respondents, it would be more efficient and cost effective for metropolitan municipalities who generate large volumes of heterogeneous waste (such as the CoCTMM) to recover energy from waste using incinerating. One of the key criteria for establishing incineration plants is minimum feedstock quantities for the investment to be economic. At least 500 tpd are required to initiate a feasible incineration technology (J Palm 2015, pers. comm., 11 August). Thus CoCTMM is in a good position to establish incineration plants unlike the other smaller municipalities, due to the better economy of scales.

On the other hand AD technologies are more suitable for the smaller municipalities as this technology is viable at small scale. The organic fraction could be mixed with waste water and sewage sludge (which includes industrial and organic-food waste streams) to improve the feedstock volumes and consequently the amount of energy recovered (J Palm 2015, pers. comm., 11 August).

Table 27: Range of important Waste Parameters for the viability of Energy Recovery

Waste Treatment Method	Basic principle	Important Waste Parameters	Desirable Range
Thermo-chemical conversion ▪ **Incineration** ▪ **Pyrolysis** ▪ **Gasification**	Decomposition of organic matter by action of heat	▪ Moisture content/ Organic ▪ Volatile matter ▪ Fixed Carbon ▪ Total Inerts ▪ Calorific Value (Net)	▪ < 45 % ▪ 40 % ▪ < 15 % ▪ < 35 % ▪ >1200 k-cal/kg
Bio-chemical Conversion ▪ **Anaerobic Digestion**	Decomposition of organic matter by microbial action.	▪ Moisture content ▪ Organic/Volatile matter ▪ C/N Ratio[29]	▪ >50 % ▪ 40 % ▪ 25-30

(Ministry of Urban Development-New Delhi, 2000)

[29]C/N Ratio = Carbon to Nitrogen Ratio, which is used to determine important chemical parameters, for example to determine the suitability of solid waste for composting.

Chapter Six: Conclusion and Recommendations

"If you wish to move mountains tomorrow, you must start by lifting stones today" – African Proverb

6.1 Conclusions

This study has investigated the potential of waste to energy technologies in addressing various socio-economic challenges facing municipalities in the context of South Africa and specifically in Western Cape Province. On the basis of a conceptual framework that links growing urbanisation and related waste management with urban energy poverty, the study explored the waste management challenges facing municipalities and the potential of resolving urbanisation challenges by integrating waste to energy into urban waste management. Using mixed methods research approach, the study identified several barriers to the implementation of WtE projects in South Africa through consultations with key stakeholders and municipal policymakers.

Given the increasing urban population, growth in waste generation, dwindling landfill space and energy supply shortfalls in South Africa, there is a growing need to consider innovative ways of dealing with these socio-economic challenges. Developing integrated waste management strategies that incorporate waste to energy is one such possibility which municipalities can adopt to deal with both waste management and energy supply issues. Currently, waste is being predominantly disposed of in landfills in South Africa but landfill space is dwindling and this will eventually make waste disposal more costly in the near future. Despite some steps towards designing integrated waste management strategies, there are limited activities on waste to energy in South Africa. Waste is generally not valorised although there are some recycling and waste minimisation programmes in some municipalities. Generally the municipalities do not have the resources and capacity to develop a WtE industry. However, the WtE technologies are gradually being deployed in many countries globally, including some parts of South Africa.

As part of managing waste, some municipalities in the Western Cape have implemented measures such as recycling and compositing. From a policy and regulatory perspective, national and local policies such as the National Environmental Management: Waste Act, IDPs and IWMPs provide a platform to consider WtE technologies but they do not directly promote it. Nonetheless, there are some activities being undertaken including feasibility studies but no

WtE has been implemented yet in the province. Thus, WtE schemes are currently not part of the waste management in the province due to various barriers. These barriers include:

1. Unsuitable waste feedstock for energy generation and poor data on waste generation and composition for investment decision making,
2. Restrictions on independent power producers of electricity to directly supply power to municipalities as well as timeous wheeling agreements (monopoly of Eskom)
3. Poor synchronisation of policies (energy and waste policies do not provide a solid platform for establishing WtE industries),
4. Poor integration of WtE into waste management planning,
5. Limited knowledge of technologies by decision makers and lack of political will;
6. Low landfill tariffs,
7. Limited access to capital to invest in technologies and high investment costs depending on the type of technology,
8. Lack of skills to implement technologies,
9. Limited awareness of the technologies and their benefits and opposition from the public for various reasons including emissions of hazardous gases, and
10. Delays in processing environmental and legal applications.

Despite the challenges there is potential for municipalities to recover energy through WtE schemes but the potential differs by location due to differences in type and amount of waste. Due to the larger volumes of waste generated, the CoCTMM could potentially generate significant amount of electricity to supply its local economy. CoCTMM' s total potential energy recovery was estimated to be 1,800 GWh against a demand of 10,256 GWh (and thus WtE could potentially meet about 17% of the city's energy supply needs). Other municipalities could meet 3% to 7% of the current electricity demand from WtE schemes. Hence, implementing WtE schemes in the selected municipalities could make some limited contribution to addressing the electricity shortfalls in the province – on condition that the WtE schemes are economically viable. Thus, WtE can contribute to both energy supply and also as an alternative method of managing waste and curbing carbon emissions. The WtE facilities can contribute to the so-called small scale embedded generators which, in spite of small their capacities in some instances, can still play a significant role in stabilising the local network and firming the power in the municipalities, and thus reduce the need for load shedding. Furthermore, WtE schemes should be seen part of broader measures in integrated waste management strategies so as to capture the additional waste management benefits.

Given the quantities and type of waste, it can be concluded therefore that the smaller municipalities cannot recover enough energy to address demand on a large scale neither can they adopt incineration as a preferred technology. It would be efficient economically for the smaller municipalities to adopt AD technologies since this can be implemented on a small scale. Larger municipalities (metropolitans such as CoCTMM) can recover energy on a larger scale using both incineration and AD technologies. Other technologies such as gasification and pyrolysis are currently not preferred as there is limited experience in implementing them and therefore carry investment risks.

6.2 Recommendations

Table 28 provides recommendations for each of the identified challenges to enable the wide scale deployment of WtE technologies. Further recommendations are discussed below the table.

Table 28: Summary of Recommendations

Adoption Challenge	Recommendation
Poor data on waste generation and composition	1. Local municipalities should consistently collect (using weighbridges) and document waste generation and disposal in their jurisdictions, this information should be fed into a centralised database such as SAWIC.
	2. Provincial and National governments are encouraged to monitor and evaluate the quality and type of information on waste to enable better policy and strategy formulation.
Restrictions on independent power producers to directly supply power to municipalities as well as timeous wheeling agreements (monopoly of Eskom)	1. National regulations should be amended to allow municipalities to enter into power purchase agreements with small scale and independent embedded generators of electricity to ensure that investment in WtE facilities is promoted, without having to follow protracted legal routes.
	2. Municipalities that are able to generate electric energy and use it for energy intensive municipal operations should be encouraged to do so. This can be achieved by exploring or tapping into un-rehabilitated landfills and co-digestion (of organic MSW and sewage waste).
Poor integration of WtE into waste management planning	1. Municipalities should consider investigating promising WtE technology options as part of the broader integrated waste management strategies and to conduct feasibility studies (with support from policy-makers).

Adoption Challenge	Recommendation
	2. Municipalities in close proximity (e.g. CoCTMM, DLM and SLM) should consider establishing a regional integrated waste management facility which encompasses existing waste management activities such as recycling to include WtE facilities. This will reduce transport costs, increase waste quantities for better output and deter landfilling of unprocessed waste.
Limited knowledge of technologies by decision-makers and political will	1. Targeted training and capacity building of key stakeholders and policymakers should be conducted in collaboration with training institutions and research institutions conducting research and development (R&D) in the WtE industry.
	2. It is recommended that decision makers undertake study tours to countries that have successfully implemented WtE schemes (e.g. Netherlands, Germany, Sweden, and South Korea) familiarise and get first-hand knowledge on the process and requirements for implementing the WtE technologies.
Low landfill tariffs	1. Landfilling of waste is set to remain in the short to medium term but the practice should be rationalised against other socio-economic and environmental considerations. It could be necessary to revise the current tariffs taking into account the externalities associated with landfilling and the benefits of alternative waste management strategies. Only inert, unusable waste material should be landfilled.
Capital to invest in technologies	1. It is important for competitive financing vehicles to be developed to support WtE schemes. This type of finance could be in the form of international green funds or climate related support finance to bridge the financing gap that could be required to unlock the capital investment in the sector. Local potential funding institutions include Development Bank of Southern Africa (DBSA), Industrial Development Corporation (IDC), and Municipal Infrastructure Grant (MIG).

Adoption Challenge	Recommendation
	2. It is recommended that Provincial (and National) governments could facilitate the easier establishment of PPPs – while still adhering to the MSA and MFMA. This is likely to attract more investment from private sector and utilise options such as Built, Operate and Transfer (BOT), Build, Own, Operate, Transfer (BOOT),etc.
Lack of skills to complement technologies	1. Municipalities should partner with tertiary institutions such as CPUT, UCT and UWC, and develop a critical mass of technical expertise to sustain any WtE programme. This can be done by providing either scholarships, learnerships or vacation work opportunities to students who are conducting applied research on WtE (in line with municipal challenges or feasibility studies).
Limited awareness and opposition from the public	1. To enable the appreciation of WtE projects, municipalities should raise awareness and clarify the benefits of WtE schemes to the public. For instance, findings from the feasibility study should be presented during the IDP public consultation process.
	2. Municipalities should use their marketing and media platforms such as pamphlets, websites, school programmes to communicate information on WtE schemes.
Delays in processing environmental and legal applications	1. Current waste management activities are hindered with delays in processing applications. This is not a simple situation that local municipalities alone can address. With the assistance of Provincial and National governments as well as input from industry practitioners, the current processes could be amended and simplified before adding an additional activity.

Further recommendations pertain to the recognition of WtE schemes in policy frameworks and programmes as discussed below:

More recognition of WtE schemes in policy frameworks and programmes

In addition to the recommendations above, WtE schemes should be considered more as an additional waste management method with the possibility of providing complementary power generation options particularly as small-scale off-grid facilities. In the next amendments to policies such as NEM: WA and NWMS, WtE schemes should be included, alongside other policies relating to climate change, energy efficiency and energy poverty. Secondly, support through subsides and incentives could also leverage investment particularly from the private sector. WtE is currently recognised in the REIPPPP under 'landfill gas' and 'biogas' but on a relatively small scale with restrictions on generation capacity (1MW or more). Also, there should be promotion of research and development (R&D) projects on a cost sharing basis, and assist with monitoring and performance evaluation of activities in the WtE sector. Lastly, there is need to assess the economic viability of various waste to energy technology options and establish more clearly the feasibility of the available technologies.

6.3 Scopes for future work

The main limitation to the study included limited availability of quantitative information on WtE trends and activities in South Africa. The local municipalities interviewed indicated that their feasibility studies were not available for public consumption until internal protocols had been concluded. Aspects of future research include (1) investigating how WtE can be incorporated from a strategy perspective within the urban planning, waste management and human settlement realms. There are further opportunities to (2) explore for wastewater-to-energy initiatives, (3) promote WtE technologies at community-scale as part of expanding residential energy mix (provide gas for heating and cooking as an alternative to paraffin) as well as (4) provide infrastructure for co-digestion.

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Annexure A: Letter of Consent

Energy Research Centre
University of Cape Town
Private Bag
Rondebosch, 7701
South Africa
April 2015

Dear Waste Management (Director)

RE: Appointment for Interview for completion of a Master's Thesis
I am Masters Student at the University of Cape Town carrying out an interview on the challenges impeding local municipalities in the Western Cape from adopting waste-to-energy schemes. The study topic is titled 'Waste-to-energy Technologies: Challenges impeding adoption in South African Local Municipalities'. The study is being carried out as a partial fulfilment of my thesis for the award of Master of Energy and Development Studies degree.

This study aims to investigate the feasibility and challenges hindering local municipalities from adopting waste-to-energy schemes as an option to enhance current waste management options and address energy demand. The objectives of the study are therefore to:

1. Investigate existing waste management methods, challenges experienced and proposed interventions;
2. Investigate whether local municipalities have considered implementing waste-to-energy schemes in the past or in the future, and the challenges they have encountered;
3. Estimate the amount of energy that can be produced by local municipalities from waste and the potential contribution to local energy demand and energy poverty reduction;
4. Identify the most appropriate waste-to-energy technology that could be deployed by local municipalities.

Attached to this letter are questions seeking general information about your waste management and the interview questions for your perusal and consideration. These close- and open-ended questions are designed to acquire information from selected local municipalities in the Western Cape on their proposed or existing usage of waste-to-energy schemes.

Kindly provide indicate if you would be available for an interview from the 1st of April until the 12th of June 2015. Your co-operation would be highly valuable and the information you provide would be treated confidentially and used only for the purposes of this study. Summary of analysis will be provided after the completion of the study. Thank you in advance for your cooperation.

Yours sincerely,

Gamuchirai T Mutezo (Miss)
Student No: mtzgam001
mutezo.gamuchirai@gmail.com
076 574 0796

Annexure B: Key Informant Interview Questions

SECTION 1: DEMOGRAPHIC PROFILE

Municipality	
Population Size	
Department	
Position	

SECTION2: WASTE GENERATION, TYPES AND MANAGEMENT OPTIONS

2.1 How much waste is generated on an annual basis? (Tonnes or m^3)

____

____

2.2 Please characterise the waste generated in your jurisdiction using the following table as a guide:

Type	Tick	% Composition out of 100
Construction & demolition		
Glass		
E-waste		
Metal		
Organic (food stuff, plant material, etc.)		
Non-recyclable		
Paper		
Plastic		
Tire (rubber)		
Waste water		

2.3 Please explain how the waste management process in your jurisdiction is carried out from collection to sorting and disposal:

____

____

____

____

2.4 Which of the following waste management options is your municipality currently implementing?

Option	Tick	Describe how this is done and where this is done in terms of the process, locations, institutions involved, technologies applied, use of products like compost and type recycled material, etc.
Composting		
Landfill		
Incineration		
Recycling		
Reuse		
Waste-to-Energy		
Other		

2.5 Please indicate the challenges and/or successes your municipality experiences.

____

____

____

____

SECTION 3: FINANCIAL CONSIDERATION FOR WM IN JURISDICTION

3.1 What percentage of the municipal budget is set aside for waste management on an annual basis? You are welcome to provide the actual amount in rands.

____

3.2 Has this percentage/ amount increased or decreased over the past five years?

	Tick	Please indicate margin in percentage (%)
Increased		
Decreased		

3.3 In your opinion, is the budget sufficient?

	Tick	Please explain
Yes		
No		
Indifferent		

3.4 What are the most expensive aspects of managing waste?

	Tick	Please explain
Service provider		
Labour		
Maintaining landfill		
Maintaining equipment		
Sorting waste		
Transportation		
Other (specify)		

3.5 Please explain the broader cost to society on land for landfills, leaching into water tables and any other negative aspects of current waste management:

____

____

____

____

SECTION 4: POLICY AND REGULATORY FRAMEWORK

4.1 Do you have policies/ regulations/ by-laws which govern waste management at local municipality level?

	Tick	Please list them and explain/ describe	Year
Yes			
	1	E.g. Integrated Waste Management Plan -	
	2		
	3		
	4		
No			

*please provide a copy of policies and/or frameworks.

4.3 Which of the waste management options are prioritised the aforementioned plans and strategies?

Option	Tick
Composting	
Landfill	
Incineration	
Recycling	

Option	Tick
Reuse	
Waste-to-Energy	
Other (specify)	

SECTION 5: WTE TECHNOLOGIES

5.1 Is your municipality currently considering or implementing waste-to-energy (WtE) technologies? Please indicate current status and explain.

Note that current status: Implemented, Feasibility Study, Sourcing Funding, On Hold

	Current Status	Please explain
Yes		
No	*(please explain)*	

5.1.1 If you answered yes to 5.1, which technology (ies) are you considering or have already implemented in your LM?

	Technology	Tick	Please explain why and provide details and reference to project documents if there are available
Non-Thermal	Anaerobic digestion		
	Mechanical biological treatment		
	Microbial Fuel Cell		
	Other		
Thermal	Combustion		
	Gasification		
	Pyrolysis		
	Other		

5.1.2 If you answered no to 5.1, please describe in as much detail as possible, the factors/ challenges hindering your local municipality from implementing WtE schemes:

5.2 In your opinion, which WtE technologies are suitable for your municipality, the Western Cape (and South Africa)?

	Technology	Tick	Please explain
Non-Thermal	Anaerobic digestion		
	Mechanical biological treatment		
	Microbial Fuel Cell		
	Other		
Thermal	Combustion		
	Gasification		
	Pyrolysis		
	Other		

5.3 If you are already implementing a WtE technology, what challenges have you experienced?

Technology	Please explain
(indicate)	
(indicate)	
(indicate)	

5.4 Which form of energy is being/ can be harnessed?

Energy	Tick	Quantity/day/month/annum	Usage
Electricity			
Gas			
Heat			

5.5 How would you rate the effectiveness of the technology as a waste management option?

Energy	Tick	Please explain
Not effective		
Effective		
Highly effective		
Not sure		

SECTION 6: ENERGY DEMAND AND SUPPLY

6.1 Please indicate the electricity demanded and supplied in your municipality

	KWh	
Demand		
Supplied		

6.2 Are there any local power plants in the area? Please list

____

____

6.3 Do you reckon the amount of energy derived from current WtE activities is making a difference in the municipality's/ province's energy demand?

	Please explain
Yes	
No	
Additional comments	

SECTION 7: FUTURE CONSIDERATION FOR WTE SCHEMES

7.1 Can the adoption of WtE schemes at local municipality level make a difference from an environmental and financial perspective?

	Tick	Please explain
Yes		
No		
Indifferent		
Not sure		

7.2 Please explain some of the advantages/opportunities (that can be) attained from waste-to-energy schemes:

____

____

____

____

7.3 In your opinion, please explain why South Africa has not adopted these schemes at the same rate as Europe, Asia and North America?

7.4 What do you think can be done to encourage waste-to-energy scheme adoption at the following government spheres?

7.4.1 Local Government

7.4.2 Provincial Government

7.4.3 National Government

Thank you for participating.

Annexure C: Assessment of Ethics in Research Projects

EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer (Zulpha.Geyer@uct.ac.za; Chem Eng Building, Ph 021 650 4791). Students must include a copy of the completed form with the thesis when it is submitted for examination.

Name of Principal Researcher/Student: Gamuchirai Mutezo Department: ERC (Energy Research Centre)

If a Student: Degree: MPhil Energy and Development Studies Supervisor: B. Batidzirai

If a Research Contract indicate source of funding/sponsorship: NRF (National Research Fund)

Research Project Title: Waste-to-energy technologies: Bottlenecks impeding adoption in South African local municipalities.

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	~~YES~~	NO
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	YES	~~NO~~
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	~~YES~~	NO
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	~~YES~~	NO

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:

	Full name and signature	Date
Principal Researcher/Student:	Gamuchirai Mutezo [signature]	12 February 2015

This application is approved by:

Supervisor (if applicable):	Bothwell Batidzirai [signature]	12.02.2015
HOD (or delegated nominee): Final authority for all assessments with NO to all questions and for all undergraduate research.		
Chair: Faculty EIR Committee. For applicants other than undergraduate students who have answered YES to any of the above questions.	G. Sithole [signature]	14/05/2015