Evaluating the technical and economic feasibility of large scale municipal solid waste to energy project in RSA – Atlantis Foundries anaerobic digestion project Case study

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Declaration

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

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Date: 28 May 2015

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Abstract

This dissertation investigates the techno economic feasibility of a large scale municipal solid waste (MSW) to energy project in the Republic of South Africa, by evaluating the feasibility of Atlantis Foundries (AF) envisaged anaerobic digestion project. Following an audit on the AF site and consultations with AF and Anaergia (PTY) Ltd (the envisaged project technology provider), the most suitable project scenarios under various assumptions were identified and used in the analysis of this study. The feasibility of 2MW continuous, 3MW continuous, 5MW continuous, 5MW peak and standard, 5MW peak and 10MW peak, MSW to energy generation project scenarios were investigated. For each scenario a basic process design was made. A dedicated techno economic model was developed, and parameters obtained from the site audit and design stages were input to the model. Results of the feasibility study were then evaluated and compared with each other. Results showed that all the project scenarios are technically feasible, legally achievable and financially feasible with payback times below 10 years and IRR above 10%. The 5MW peak and standard generation scenario is the most economically attractive option with a payback time of 5.2 years and IRR of 23%, followed by the 5MW continuous generation scenario with a payback time of 5.7 years and IRR of 21%. The 5MW peak and standard generation scenario can offset about 134,000 tonnes of CO2 equivalent GHG emissions per year.

Synopsis

Climate change and global warming caused by increasing greenhouse gas (GHG) concentrations in the atmosphere is one of the world's most pressing challenges. It is predicted that climate change will have disastrous global effects if it is not seriously addressed. Africa and South Africa are considered to be especially vulnerable to climate change (Pegels, 2009), yet South Africa is the largest emitter of GHG in Africa, contributing over 40% of Africa's total CO2 emissions (DEA, 2009).

South Africa also suffers from energy problems. Recent load shedding and Eskom's poor financial state are some of South Africa's energy problems including but not limited to: energy security, energy poverty, negative environment impacts, high energy cost, etc. (Creamer Media, 2014).

Municipal solid waste (MSW) management is becoming a major challenge globally and especially in developing countries. Landfilling of MSW is the most common practice of waste disposal, especially in developing countries, this is mainly due to relative simplicity and low costs associated with landfilling (Domingo and Nadal, 2009; UNEP, 1996). Environmental concerns, rising cost of landfilling and limited landfilling space are some of the challenges (Couth and Trois, 2010). The most common challenges associated with landfilling are land availability (especially in big cities), increasing costs of new landfills and waste transportation, toxic leaches, odors, and landfill gas emissions. Landfill gas is also a concern since it has a high methane content of about 50% as well as a high carbon dioxide content. Methane has 21 times the GHG (greenhouse gas) effect of carbon dioxide (Clemens et al., 2006) and therefore landfilling poses a climate change risk (Domingo and Nadal, 2009; Pognani et al., 2010).

The three challenges mentioned above – climate change, energy and MSW management can be addressed by conversion of waste to energy using renewable energy technology. Anaerobic digestion (AD) of MSW accompanied with renewable energy recovery is an ideal solution for addressing waste management, climate change and energy supply (Greben et al., 2009). AD is a well-established technology (Lettinga, 1996). The process of AD is the biodegradation of organic materials, in the absence of oxygen, by anaerobic bacteria. The AD process occurs naturally in organic matter; the natural and artificial AD process has been utilized for many uses, most commonly to stabilize waste water sludge (Janssen, 2010).

The results of the process are methane rich biogas (typically 50-70% methane content) and stabilized sludge. Methane has a high calorific value and is major constituent of natural gas, therefore the biogas can be used as a renewable energy source. The sludge has high nitrogen, carbon and other plant nutrition values and can be used as an organic fertilizer (Ahring, 2003). AD of MSW has the potential to generate 75-150 kWh per ton of MSW (Braber, 1995).

This study investigated the techno economic feasibility of a large scale municipal solid waste (MSW) to energy project in the Republic of South Africa, by evaluating the feasibility of the proposed Atlantis Foundries (AF) anaerobic digestion project. The main objective of this study was to contribute to the knowledge gap concerning a specific techno economic feasibility of a large scale MSW AD to energy project, in the context of Cape Town, South Africa.

The methodology used in this study was to first conduct site audit at AF, including data gathering and interviews. The information collected was used to identify the most suitable MSW AD to energy generation scenarios for AF.

With Anaergia Africa (PTY) Ltd (the proposed project technology provider) support, technical aspects, design and costs were determined for each scenario. With the support of Chand Environmental Consultant (PTY) Ltd (the envisaged project environmental consultant), the legal requirements for the Atlantis project implementation were identified.

The feasibility of 2MW continuous, 3MW continuous, 5MW continuous, 5MW peak and standard, 5MW peak and 10MW peak, MSW to energy generation project scenarios were investigated. For each scenario a basic process design was made. The investigation of energy generation during different electricity tariff times was made to explore the effect of the different electricity tariffs on the project feasibility.

An Excel model was developed to investigate the feasibility of the technical and economic aspects of the project. The information gathered for each project scenario was fed into the model and key technical and financial indicators for each scenario were compared. Sensitivity analysis were conducted on the scenarios to test the robustness of the results of the different scenarios.

This study has shown that it is technically and economically feasible to establish a large scale MSW AD to energy facility linked to a specific industrial load in Cape Town, South Africa. The results also show that all the selected project scenarios are technically feasible, legally achievable and financially feasible. Given the current electricity tariffs in South Africa, the evaluation has shown that the most attractive energy generation scenario is to establish a waste to energy plant at a scale of 5MW and operate it as a peaking as well as standard generation plant. Thus the "peak and standard" scenario was found to be optimal economically and has a payback time of 5.2 years, twenty years IRR of 23%, an NPV of about 316 million Rand, which exceed Antlatis Foundry minimum project feasibility requirements. Using 132,000 tonnes of waste, the facility is designed to produce about 1,600 m^3 of biogas per hour and generate 28.2 GWh of electricity.

Adequate waste is available from the waste to energy facility, enough waste is available to provide the required 210,000 tonnes per year for a 5 MW continuous. The continuous plant is less competitive compared to the 5 MW peak and standard plant as the investment returns are weaker for that scenario. Thus avoiding off-peak generation could improve the business case. However, the waste to energy plants could provide base load to the electricity supply system unlike other renewables such as solar and wind, and this could be supported by policy to encourage investors to establish continuous plants. The peak generation scenarios are less favourable economically due to the poor return on investment as their operation is restricted to only a few peak hours.

The proposed plant is also attractive as it is to be located close to Vissershok landfill (one of the biggest landfills in the Western Cape) and therefore provides a key favorable attribute for a waste to energy project, the shorter the transportation distance from source of waste to energy conversion facility, the

better the economics of the value chain. Thus proximity of a waste to energy facility to large landfills improves the feasibility of the waste to energy project.

Antlatis Foundry provides a ready market for the facility's electricity and heat output as its continuous and intensive mode of operation and high energy demand presents a continuous and large renewable energy off-take opportunity for a waste to energy project - a precondition for the successful deployment of waste to energy technologies.

There is therefore a strong business case for establishing the waste to energy facility at the Atlantis Foundry site, apart from the additional environmental benefits. AF's relatively high electricity consumption during peak and standard tariff times, strongly supports the business case of a waste to energy project. Hence, similar projects should be investigated with other large electricity consumers with high peak and standard demand. The chosen 5MW P&S scenario will result in a GHG emission avoidance equal to 150 kiloton of CO_2 per year, which could strengthen the project case and may result in significant financial benefits in the future in terms of carbon credits. Also AF current industrial permits (including air emission license) makes securing of environmental and legal permits for the waste to energy project easier. Thus, heavy industries are good candidates for waste to energy projects since they have established environmental permissions processes.

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Acronyms

Notation	**Definition**
AD	Anaerobic Digestion
AF	Atlantis Foundries
AIA	Archaeology Impact Assessment
BMP	Bio-methane potential
(C)	Continuous (electricity generation)
(C:N)	Carbon to Nitrogen (ratio)
Capex	Capital Expenditure
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
CoCT	City of Cape Town
CoD	City of Durban
CSTR	Complete Stirred Tank Reactor
DEA	Department of Environmental Affairs
DM	Dry Matter
DOE	Department of Energy
DOC	Degradable Organic Carbon
DTI	Department of Trade and Industry
DWAF	Department of Water Affairs and Forestry
EA	Energy Activity
EBITDA	Earnings Before Income, Tax, Depreciation and Amortization
EF	Emission Factor
EIA	Environmental Impact Assessment
EPC	Engineering Procurement and construction
FA	Free Ammonia
GDP	Gross Domestic Production
GGP	Gross Geographic Product

GHG	Green House Gas
GIS	Geographic Information System
GJ	Gigajoule
HFO	Heavy Fuel Oil
HIA	Heritage Impact Assessment
HRT	Hydraulic Retention Time
IWMS	Integrated Waste Management Systems
IWMP	Integrated Waste Management Plan
IRR	Internal Rate of Return
LCFA	Long Chain Fatty Acids
LPG	Liquefied Petroleum Gas
MCC	Motor Control Center
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
MWSP	Municipal Waste Sector Plan
NCCRGP	The National Climate Change Response Green Paper
NCF	Net Cash Flow
NEMA	National Environmental Management Act
NEMWA	National Environmental Management Waste Act
NPV	Net Present Value
NWMS	National Domestic Waste Collection Standards
OFMSW	Organic Fraction of Municipal Solid Waste
O&M	Operation and Maintenance
OLR	Organic Loading Rate
Opex	Operational Expenditure
OX	Oxidation Factor
(P)	Peak only (electricity tariff)

(P&S)	Peak and Standard only (electricity tariff)
PLC	Programmable Logic Controller
PPM	Particles Per Million
PSA	Pressure Swing Adsorption
RDF	Refuse Derived Fuel
REIPPP	Renewable Energy Independent Power Producers Program
ROI	Return on Investment
SCADA	Supervisory Control And Data Acquisition
SEZ	Special Economic Zone
SRB	Sulphate Reducing Bacteria
SRT	Solid Retention Time
SSO	Source Separated Organics
TDS	Total Dissolved Solids
TKN	Total Kjedhal Nitrogen
UN	United Nations
UNEP	United Nations Environmental Program
USA	United States of America
US EPA	United States Environmental Protection Agency
VFA	Volatile Fatty Acid
VS	Volotile Solids
WWTP	Waste Water Treatment Plant

1. Introduction and Background

Climate change is one of the world's most pressing challenges. It is predicted that climate change will have disastrous global effects if it is not seriously addressed. The African continent is one of the most vulnerable continents in the world to climate change (Pegels, 2009). South Africa has been identified as one of the vulnerable African countries to climate change, and water scarcity and rising sea levels are some of the major concerns (Pegels, 2009; DEA, 2010).

Climate change is a result of increasing greenhouse gas (GHG) concentrations in the atmosphere, which cause global warming. GHG are released mainly as a result of human activities such as burning fossil fuels and conversion of land (IPCC, 2007). South Africa is the largest emitter of GHG in Africa, contributing over 40% of Africa's total CO2 emissions. In 2000 it was estimated that 79% of South Africa's GHG emissions resulted from its energy sector (DEA, 2009), and in 2009 South Africa emitted 511 million tons of CO2 equivalent, 85% of which are attributed to the energy sector (DEA, 2009).

South Africa electricity generation accounts for two-thirds of Africa's electricity generation and is one of the cheapest electricity producers in the world. Most of South Africa's installed power generation capacity - about 93% - is based on coal and centralized around the coal mining area of Mpumalanga. Eskom, the state owned utility, supplies about 90% of South Africa's electricity (BP, 2013). On the other hand, South Africa imports most of its oil products and consumed about 800 PJ of oil in 2010. South Africa's oil consumption is mainly used by its transportation sector (Merven et al, 2012).

South Africa's electricity system has been facing some challenges lately, recent load shedding and Eskom's poor financial state are some of South Africa's energy problems including but not limited to: energy security, energy poverty, negative environment impacts, high energy cost, etc. (Creamer Media, 2014).

Cape Town is heavily reliant on the national utility Eskom for its electricity supply (SEA, 2007). It is estimated that 95% of Cape Town's electricity comes from Eskom's coal fired power stations in the north of the country while only 5% are provided from Cape Town's nuclear power station Koeberg* (SEA & AMATHEMBA, 2007). This is undesirable, due to the long electricity transmission distance and the associated transmission loses (Winkler et al., 2005).

South Africa's government has initiated policies and programs to reduce its GHG emissions. The National Climate Change Response Green Paper (NCCRGP) and the Renewable Energy Independent Power Procurement Program (REIPPP) are evidence of South Africa's attempt to mitigate its GHG emissions and address its energy challenges. The renewable energy technologies considered by South Africa include biomass, solar, wind and hydro, where wind and solar technologies take the lion share of the REIPPP program (DEA, 2010). Out of these technologies, waste to energy is the only one that addresses climate change, energy and waste management.

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* Electricity generated at Cape Town's Koeberg Nuclear Power Station feeds directly into the national grid, and ELECTRICITY SUPPLY TO THE City of Cape Town ARE CONSIDERED to be the same as that of the rest of the country (Cape Town, 2011)

Municipal solid waste (MSW) management is becoming a major challenge globally and especially in developing countries. Environmental concerns, rising cost of landfilling and limited landfilling space are some of the challenges (Couth and Trois, 2010). The MSW challenge is aggravated by the fact that the amount of MSW is increasing in direct correlation with population growth and GDP (Gross Domestic Production) growth coupled with migration from rural settlements to big cities, which exacerbates the problem (Klass, 1998; Thomas, 2006). The changing nature of MSW in place and time also makes it difficult to find a uniform solution to the MSW challenge. The nature of MSW is typically a function of climate, culture, food sources, income, etc. (Cointreau-Levine and Sandra, 1994; Troschinetz and Milheclic, 2009)

Landfilling of MSW is the most common practice of disposal, especially in developing countries, this is mainly due to relative simplicity and low costs associated with landfilling (Domingo and Nadal, 2009; UNEP, 1996). The most common challenges associated with landfilling are land availability (especially in big cities), increasing costs of new landfills and waste transportation, toxic leaches, odors, and landfill gas emissions. Landfill gas has a high methane content of about 50% as well as a high carbon dioxide content. Methane has 21 times the GHG (greenhouse gas) effect of carbon dioxide (Clemens et al., 2006) and therefore landfilling poses a climate change risk (Domingo and Nadal, 2009; Pognani et al., 2010).

Landfilling in South Africa is also a growing concern, South Africa's large cities generate more MSW than most European cities, at an average rate of 2 kg per person per day (Von Blottnitz et al., 2007). Most of South Africa's MSW is disposed in landfills, and given South Africa's MSW high organic content of about 40-50% (DEAT, 2006 cited in Pegels, 2010), it is estimated that landfill gas is responsible for 2% of South Africa's GHG emissions (DEA, 2010).

The challenges of MSW are also evident in Cape Town. A study by Jeffares&Green and IngeropAfrica (2004) found that 87% of Cape Town's waste is landfilled and that household waste contributes 38% to the total MSW. This is further supported by a study done by the City of Cape Town (2011) that found that household waste makes 46% of the city's MSW. This also aligns with a study done by Gilbert, et al. (2014) that showed that the organic fraction of MSW (OFMSW) contributes an average of about 36% to the total MSW composition. The high landfilling rate and organic content of Cape Town MSW, points towards a GHG problem (Jeffares&Green and IngeropAfrica, 2004; CoCT, 2011; Gilbert, et al., 2014).

Another MSW challenge in Cape Town is that all three active landfills in Cape Town: Vissershok, Coastal Park and Bellville South, are reaching their full capacity. An EIA study for a new landfill site has commenced in 2000 but has been stuck in legal difficulties since 2008, mainly due to limited land space and lack of public support for new sites near the city (CoCT, 2007; Jeffares&Green & IngeropAfrica, 2004).

Integrated waste management systems (IWMS) offer a solution to the growing MSW challenge. IWMS approach MSW with a holistic view, prioritizing strategies of waste avoidance, reduction, recovery, recycling and energy extraction, with landfilling as the last priority (Palczynski, 2002; USEPA, 2002).

Comparing a study done by Sakai et al. (1996) and data retrieved from Eurostat (2009), shows that the amount of waste landfilled was reduced by an average of about 49% in some European countries. Both studies also revealed a relatively high percentage of incineration in developed countries, this can be attributed to the dry and high calorific nature of waste in developed countries supported by increasing rigidity and enforcement of environmental regulation (US EPA, 2002; Thomas, 2006; Mohee, 2002). Most of developed countries MSW incineration plants are accompanied with renewable energy generation in the form of heat or electricity (Thomas, 2006; Mohee, 2002).

In spite of the success of IWMS in developed countries, these systems have limited impacts in developing countries. Lack of human and financial resources and consequently the lack of infrastructure and supporting technologies are the main reasons for the limited implementation and positive impact of IWMS in developing countries (Barton et al., 2008). As with the case for IWMS, despite the demonstrated advantages of thermal processing of MSW in developed countries, it is generally considered not suitable for developing countries, (Rand et al., 2000). High operational costs, lack of supporting infrastructure and legislation, coupled with the wet nature of MSW, makes incineration unattractive for developing countries (Sakai et al,. 1996; Zerbock, 2003).

Considering the challenges of energy poverty and security, anaerobic digestion (AD) of MSW accompanied with renewable energy recovery may be an ideal solution for addressing both waste management and energy supply (Greben et al., 2009). AD is a well-established technology. Industrial applications of AD are dated back to 1895, for sewage treatment in England (Lettinga, 1996). The AD process occurs naturally in organic matter, the natural and artificial AD process has been utilized for many uses, most commonly to stabilize waste water sludge (Janssen, 2010). Artificial AD process takes place in a digester or reactor (Wilkie et al., 2008).

The process of AD is the biodegradation of organic materials, in the absence of oxygen, by anaerobic bacteria and archea. The results of the process are methane rich biogas (typically 50-70% methane content) and stabilized sludge. Methane has a high calorific value and is main constituent of natural gas, therefore the biogas can be used as a renewable energy source. AD of MSW has the potential to generate 75-150 kWh per ton of MSW (Braber, 1995). The sludge has high nitrogen, carbon and other plant nutrition values and can be used as an organic fertilizer (Ahring, 2003).

Cape Town has recently given priority to waste to energy integration in its waste management systems. A report issued by the executive mayor of the City of Cape Town regarding alternate service delivery mechanisms for solid waste management, recommended that waste to energy technologies be investigated and incorporated in support of the council's energy policy and targets, a high priority was given to the OFMSW (CoCT, 2011). Therefore landfill gas extraction and AD aligns well with the city targets.

1.1. Problem statement

Previous studies investigating the feasibility of MSW to energy projects in Cape Town do not provide detailed information on the techno economic feasibility of large scale projects. Optimum Energy Futures for Cape Town and Energy Scenarios for Cape Town (Winkler et al., 2005; SEA & ERC, 2010), considered the feasibility of waste to energy on a city scale. A study by Munganga (2011) focused on biogas production potential analysis for Cape Town at a lab scale. Mala (2011) evaluated the feasibility of a general project on a large and city scale, using estimates for the project cost and generic project technical details. AGAMA (2009) developed a feasibility model (in the form of a spreadsheet) for the South African cities network, the model is for a generic project and also uses estimations for cost and technical parameters. Thus a detailed techno economic feasibility study of a specific large scale project that takes into account project specific information regarding costs and site specific technical parameters is not available. In addition, none of these studies considered exploring different MSW AD scenarios that investigate the impact of different electricity tariff regimes.

1.2. Objective

The main objective of this study is to contribute to the knowledge gap concerning a specific techno economic feasibility of a large scale MSW AD to energy project, in the context of Cape Town, South Africa by using the AF project specific commercial information. The results of this study should therefore be useful for the private and public sector, for evaluation of similar projects. This objective can be broken down into the following sub-objectives:

1. To evaluate the technical, economic, policy/legal and environmental feasibility of establishing a municipal waste to energy plant to feed into an existing load at the Atlantis foundry site by using project specific technical and economic information from a relevant, active and commercial technology provider.
2. To contribute to the development of a MSW AD to energy industry in RSA, by demonstrating optimal scenarios for large scale projects that take advantage of electricity tariffs and consumer loads.
3. To examine the environmental benefits of large scale MSW AD projects.

1.3. Research questions

The key research questions are:

4. What MSW AD to energy generation scenarios are most suited to an industrial load such as Atlantis Foundries (AF), given prevailing electricity tariff regime in South Africa?
5. What is the technical and economic feasibility of these scenarios?
6. Which scenario is the most feasible?
7. What are the environmental impacts of the most feasible scenario?

1.4. Research approach and scope

This dissertation is based on a collaboration with Atlantis Foundries PTY (Ltd), Anaergia Africa PTY (Ltd) and Chand Environmental Consultants PTY (Ltd). AF is busy investigating renewable energy opportunities and agreed to serve as a case study for this study, Anaergia Africa is the designated project technology provider and main EPC contractor and Chand Environmental Consultants is the designated project environmental consultant.

1.5. Thesis outline

The outline of this thesis is as follow:

Chapter 2 is the literature review of this study and is divided into five sections:
Section 2.1. deals with MSW, it explains what MSW is and provide with a global and national context to MSW. IWMS are then also discussed in a global and national level and specific challenges with IWMS are explained.
Section 2.2. provides with a general review of South Africa's energy situation, in preparation for the following section discussing waste to energy.
Section 2.3. deals with anaerobic digestion technology, the AD process is explained in details, including types of AD technologies and the biological process. This is followed by a description if the main process parameter. Common types of AD feedstock and feedstock relevant to this study are described. Main process indicators assuring a smooth and optimal AD operation are explained. Uses and biogas applications are discussed followed by a review of biogas upgrading technologies. Lastly GHG emission reduction theory and calculations are explained.
Section 2.4. provides with a literature review concerning legal and environmental aspects of a waste to energy project.
Chapter 3 describes the methodology used in this study. It is divided into four main sub-sections:
Section 3.1. deals with technical aspects of this study methodology, such as the approach used to determine the project operation and production aspects, traffic impact, sizing of the project and choosing its main scenarios to be further investigated are few examples. The methodology taken to for design aspects of the study, such as the mass and energy balance, process flow etc. is also described in this subsection.
Section 3.2. deals with the methodology used to determine the economic feasibility of the different project scenarios investigated.
Section 3.3. describes the methodology used to approach legal and environmental feasibility aspects of the project.
Section 3.4. provides with explanations regarding the methodology followed to calculate GHG emission reduction resulting from the project.
Chapter 4 presents input data used in the study. It is divided into three main sub-sections:
Section 4.1. deals with technical aspects of the data used in this study. This section provides with details of information sourced from AF regarding relevant aspect of their current operations to the waste to energy project, information from relevant stack-holders such as the designated waste supplier, as well as relevant data from the project surroundings. Lastly summary of data used for the design of the project is provided including a detailed description of the process flow and philosophy and its main components.

Section 4.2. provides environmental and legal data concerning the project. This sub-section mainly deals with data collected in collaboration with the project designated environmental consultant.
Section 4.3. provides with a summary of the data used for the GHG emission reduction calculations.
Chapter 5. is the results chapter, it presents and explains the results of this study. It is divided into four main sub-sections:
Section 5.1. provides with technical results of this study. Answers to practical and technical questions concerning the project are provided and explained, for example the results of the different scenario traffic impact assessment and results of evaluation of the existing AF infrastructure with regards to the project. This sub-section also provides with the outcomes of the project design such as the project layout, mass and energy balance, etc.
Section 5.2. provides with the economic feasibility results of this study. The economic feasibility of the different scenarios investigated are presented explained and evaluated, the chosen scenario is presented and explained and finally results of the sensitivity analysis are presented and discussed.
Section 5.3. provides with results concerning the environmental and legal feasibility aspects of this study. In this subsections results and findings from the environmental investigation done in collaboration with the project designated environmental consultant, including outcomes of interviews with the relevant authorities are presented and discussed.
Section 5.4. provides with results of the GHG emission reduction calculations.
Chapter 6 presents the study conclusions and recommendations of this study.

The answers to this study key questions can be found as follows:

Sections 4.1. and 4.2. are a summary of the information received and audited from AF and the project surrounding, this information is then used in section 3.1.6. to answer the **first research question** – determining the most suitable scenarios, to be further investigated, for the case of AF MSW AD for renewable energy generation.

Section 5.1.1. to 5.1.8. presents the results of the project design. The project layout, PFD and mass and energy balance are given in sections 5.1.10. to 5.1.12. Respectively. Section 4.1.11. Presents the process design and philosophy of the waste to energy plant. These results are then used in section 5.2. to answer **research question two** – the techno-economic feasibility of each scenario. The legal feasibility of the project is discussed in section 5.3.

Section 5.2. also answer **research question three** - which scenario is the most feasible by evaluating and comparing the different scenarios feasibility.

The environmental benefits, in a form of carbon dioxide emissions avoidance, of the most attractive\feasible scenario are than calculated and explained in section 5.4. to answer **research question 4.**

2. Literature review

This chapter is divided into five main sections. Section 2.1 provides an overview of developments and challenges in global MSW and discusses innovative ways of dealing with waste including integrated waste management systems (IWMS). Section 2.2 reviews South Africa's energy situation, to provide context for the discussion on waste to energy. Section 2.3 provides an detailed overview of anaerobic digestion technology, the AD process - including types of AD technologies, biological processes, main process parameters and common AD feedstock types. This section also discusses the main process indicators for ensuring optimal AD operation as well as biogas applications. In addition, the chapter also provides an overview of the legal and environmental aspects of waste to energy projects including GHG emission issues.

2.1. Municipal solid waste

This section provides an overview of MSW, waste management and waste to energy technologies and systems. It discusses the meaning of MSW in general, in developed countries versus developing ones and in South Africa specifically. Then this section discusses integrated waste management systems (IWMS) in general. Finally it looks specifically at energy recovery from MSW and renewable energy as an aspect of IWMS.

2.1.1. What is MSW?

MSW consists of the waste that is produced and disposed from both residential and commercial sectors. MSW can contain anything but is typically limited to daily items that are consumed and thrown away by people in the mentioned sectors. MSW is often characterized by the following types of waste (Braber, 1995):

- Organic waste: food waste and garden waste.
- Recyclable materials: certain plastics, certain metals, glass, paper, etc.
- Inert wastes: stone, sand, etc.
- Composite wastes: certain plastics, fabrics, etc.
- Hazardous and toxic wastes: electronic waste, paints, chemicals, batteries, etc.

2.1.2. MSW in the world

Comparing MSW from different countries can prove to be difficult since different countries and jurisdictions within countries may define waste, sample it and characterize it in different ways and methods (Sakai et al, 1996).

MSW in developed countries tends to be quite different from waste in developing countries. In contrast, waste in developing countries tends to be denser, have higher moisture content, is lower in calorific value and have a higher organic content, this is shown in table 1 below. This can partly be explained by the higher content of packaging material in developed countries MSW and unofficial recycling and recovery of non-organic waste in developing countries. Packaging material such as plastic, glass, paper and metal, reduces the overall waste density, reduces the overall moisture content and organic content and increase the overall calorific value. Calorific value is a function of moisture and hydrogen content, and packaging material, especially plastics are rich with hydrogen and have very low moisture content (Asomani-Boateng, 1999; Troschinetz and Mihelcic, 2009; UNEP, 2009; Thomas, 2006).

Another significant difference between MSW in developed countries versus MSW in developing countries is the volumes or quantities generated. There is a positive correlation between gross national product and the amount of waste per capita. Table 1 below illustrates this principle, showing that the amount of waste per capita is 0.4-0.6 kg/day and 0.7-1.8 kg/day in developing and developed countries respectively (Thomas, 2006).

	Developing countries	**Middle-income countries**	**Industrialized countries**
Waste generation	0.4-0.6	0.5-0.9	0.7-1.8
MSW wet density (kg/m3)	250-500	170-330	100-170
H_2O %	40-80	40-60	20-30
Wt % composition			
Paper	1.0-10	15-40	15-40
Glass, Ceramics	1.0-10	1.0-10	4.0-10
Metals	1.0-5	1.0-5	3.0-13
Plastics	1.0-5	2.0-6	2.0-10
Leather, Rubber	1.0-5	–	–
Wood, Bones, Straw	1.0-5	–	–
Textiles	1.0-5	2.0-10	2.0-10
Putrescibles	40-85	20-65	20-50
Inerts (Miscallenous)	1.0-30	1.0-30	1.0-20

Table 1: Characteristics of MSW by level of industrialization
(Adapted from Thomas, 2006) (Unless specified otherwise, units are in Kg/capita/day)

There is also a direct positive correlation between MSW and population growth. For example in the USA, total annual amount of MSW generated and MSW generated per capita increased from 80 million ton per year and 1.23 ton per capita per day in 1960, to 180 million ton per year and 1.97 ton per capita per day in the 1990 (Klass, 1998).

2.1.3. MSW in South Africa

Most municipalities in South Africa do not have waste information systems and infrastructure in place to accurately measure waste disposed or diverted from landfills within their municipal boundaries (Gilbert, et al., 2014). According to the Department of Environmental Affairs (DEA), the average middle class South African produces 700 grams of MSW per day, with an average of 40% organic content, which is mostly disposed of in landfills (DEAT, 2006 cited in Pegels, 2010)*. This means that about 2.7 million tons of MSW are generated and landfilled in South Africa per year, by its middle class alone.

2.1.4. MSW in Cape Town.

The Department of environmental affairs in collaboration with Stellenbosch Municipality conducted waste characterization studies within the Central Karoo District municipalities in the Western Cape i.e. Beaufort West, Laingsburg and Prince Albert, the results are presented in the graph below (Gilbert, et al., 2014).

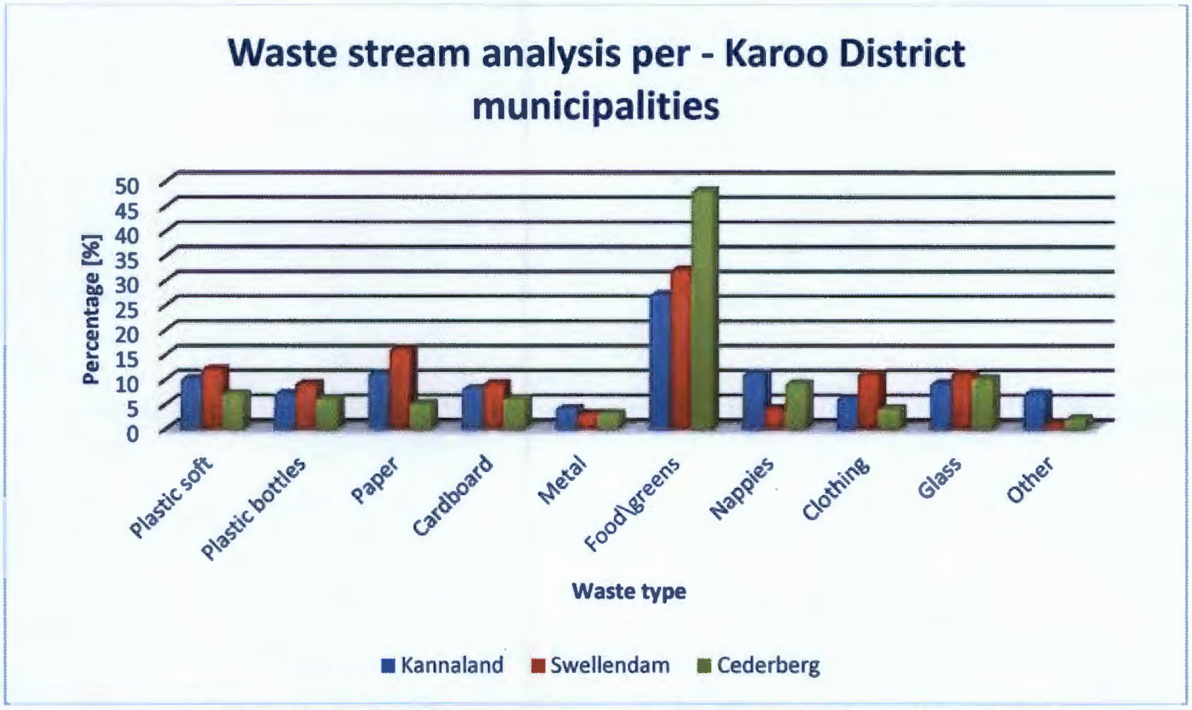


Figure 1: Waste stream analysis per municipality in the Central Karoo District (adapted from Gilbert, D.L. et al., 2014).

The graph clearly shows a high percentage of organic MSW content, of 27-48% which aligns well with the department of environmental affairs average.

Jeffares&Green and IngeropAfrica (2004) analysed the different sources of MSW in Cape Town, and Figure 2 below sows the study results. The study clearly shows that household waste is the largest source of MSW in Cape Town with a fraction of 38%.

* note that this differes from figure quated previously by Von Blottnitz et al., 2007, indicating 2kg per person per day. The difference is a result of different studies. The more conservative figure is used here.

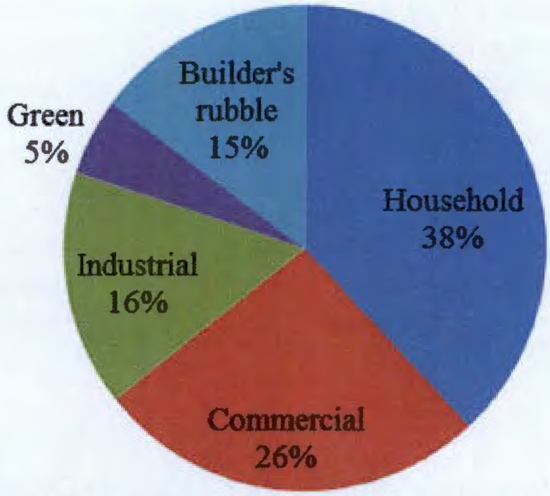


Figure 2: MSW source characterization in Cape Town in 2003
(adapted from Jeffares&Green and IngeropAfrica, 2004)

Data published by the City of Cape Town (2011) showed an increase in the household fraction of the city's MSW to 46% (CoCT, 2011). In this study, household was classified according to income groups: high, middle and low. High income earn above R72,000, middle income between R42,000 and R71,999 and low income up to R41,999 annual income and generate 2, 1.1 and 0.5 kg of waste per capita per day respectively, excluding green\garden waste (green waste consists of garden waste, municipal grass and trees trimmings, etc.). The study also characterized the composition of general household waste, figure 3 below shows the characterisation (Jeffares&Green and IngeropAfrica 2004).

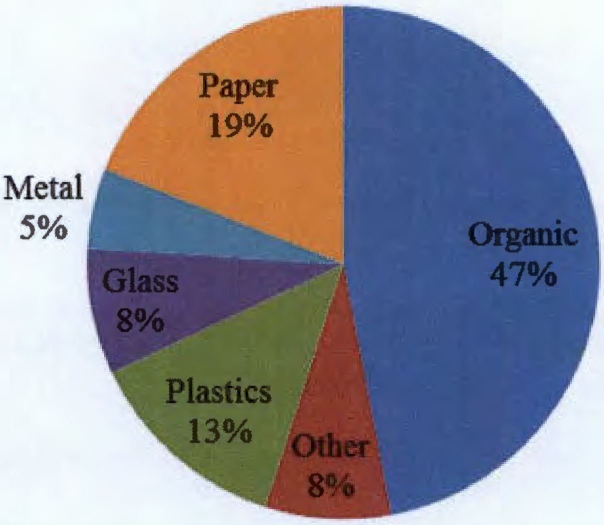


Figure 3: Characterization of general household waste in Cape Town
(adapted from Jeffares&Green and IngeropAfrica, 2004)

The city of Cape Town has three landfill sites: Coastal Park, Bellville and Vissershok, and three waste transfer stations with material recovery facilities (MRF): Athlone, Oostenberg and Kraaifontein. The material recovery facilities separate the recyclable from the non-recyclable waste, the Oostenberg is a clean MRF, the Athlone is a dirty MRF and Kraaifontein is both. A clean MRF handles source separated waste, meaning waste that was separated into recyclables and non-recyclables at source. The non-recyclable waste from all MRFs is disposed of at Vissershok (SEA & AMATHEMBA, 2007; CoCT, 2011).

One of the dominant challenges of landfilling arise from the large quantities of OFMSW (organic fraction of MSW) and their potential to generate greenhouse gas (GHG) emissions (Cuetos et al., 2008). Another disadvantage of landfilling is that landfills runs out of space as they are being used, given that landfills are expensive and take long time to build, the City of Cape Town is facing a challenge with its MSW since all three landfills at use are close to their full capacity. Furthermore, finding a new landfill site in Cape Town that is both geologically and socially acceptable is very challenging. The option of building new landfills for Cape Town far from town is also challenging due to high costs of waste transportation (SEA & AMATHEMBA, 2007). Nontangana (2011) points out that in Cape Town, the large quantities of OFMSW are a challenge to Cape Town's shrinking landfill space. Increasing dumping costs combined with low landfilling space are some of the main reasons behind Cape Town's high landfill gate fees of R333.2 per ton, which are expected to increase (Nontangana, 2011 cited from Malla, 2011; CoCT, 2014).

Two studies conducted in Cape Town by Jeffares&Green and IngeropAfrica (2004) and SEA and AMATHEMBA (2007) showed that 5,900 and 6,000 tons per day of MSW was generated in Cape Town respectively in 2004 and 2007 respectively. Jeffares&Green and IngeropAfrica (2004) also argued that there is a direct correlation between waste generation and population growth, in their study conducted in Cape Town in 2004 there was an annual increase in population and waste generation of 1.57% and 3.8% respectively (Jeffares&Green and IngeropAfrica 2004).

Another study by Akhile Consortium (2011) on Cape Town, showed a correlation between gross geographic production (GGP), population growth and waste landfilled. The study showed that for every 1% increase in population growth and GGP (Gross Geographic Product) there is 0.9% and 0.6% increase respectively in waste landfilled (Akhile Consortium, 2011). Data published by the City of Cape Town (2011), support the claims above for a positive correlation between GGP, population growth and waste generated. In 2008 when Cape Town had strong economic growth, waste generation grew by 5%, later when the economic boom phase was over, waste generation decreased (CoCT, 2011).

2.1.5. Integrated Waste management systems

Traditionally, a waste management system is the system of collecting the waste and disposing it in landfills (USEPA, 2011). From the 1970's a new approach towards waste management systems emerged in developed countries. In essence, the new approach differs from the traditional one in two main aspects: that waste shouldn't be treated as one item since it's made of very different components and that an "end pipe" approach to handling of waste, meaning landfilling it, is not a sustainable or cost effective solution. This new approach gained more momentum in the 1990's when a new waste hierarchy emerged and the new approach was adopted by more developed countries as well as in developing countries (Gertsakis and Lewis, 2003), figure 4 below shows the IWMS approach to waste hierarchy.

Figure 4: Integrated solid waste management hierarchy
(adapted from Greenstar, 2009)

In principle, the integrated solid waste management hierarchy prioritizes waste management at its source down to its disposal. Waste prevention and minimization can be achieved through interventions in manufacturing and consumption. Waste avoidance from a manufacturing perspective means more efficient utilization of material resources in products and their packaging, in order to reduce the amount of materials ending up as waste. This is mainly a function of government policies and legislation for the manufacturing sector as well as initiatives of the manufacturing sectors themselves, to become more sustainable and appealing to their consumers. From the consumers aspects, waste minimization is a function of public environmental and sustainability awareness, to consume minimum waste products and make more efficient use of products, for example by reusing products (Greenstar, 2009).

According to Sakai et al. (1996) and Palczynski (2002), the following steps of the waste hierarchy are explained:

- Re-use of products is done after collection, transportation and handling of waste, to divert it to where it can be reused, without altering its main characteristics.
- Recycling of waste is also done after collection, transportation and handling, to divert it to processing facilities that brings the waste to its raw form, which can be used again in or as a new product.
- Energy recovery means extracting the calorific value of waste as useful energy, for example by burning the waste to produce heat for process heating. There are several process and technologies to achieve this, and these are discussed extensively in section 2.8.

Waste disposal or landfilling is the least priority option which should be done after all the previous mentioned options have been explored and exhausted. Even when landfilling, the negative environmental effects can be mitigated and energy recovery can be achieved to some extent. Traditionally, landfills were designed as unlined, open dumps. New landfill designs, known as sanitary landfills, are lined to prevent leaching and are covered to allow capturing of the biogas generated in the natural biodegradation process of the organic fraction of the waste (Domingo and Nadal, 2009). Biogas contains high volumes of methane of about 40-60% and can be used for energy generation, but methane has a high global warming potential (Clemens et al., 2006), and so capturing it helps to significantly reduce the carbon footprint of landfilling. Nevertheless, even sanitary landfills are still least preferred waste management systems, due to limited land availability, high costs of sanitary landfills and increasing waste transportation costs (Domingo and Nadal, 2009).

According to Mannie and Bowers (2014) an integrated waste management system has the following three major dimensions:

- Stakeholders involved in waste management;
- The (practical and technical) elements of the waste system; and
- The aspects of the local context that should be taken into account when assessing and planning a waste management system.

The figure below illustrates these three main dimensions of an IWMS.

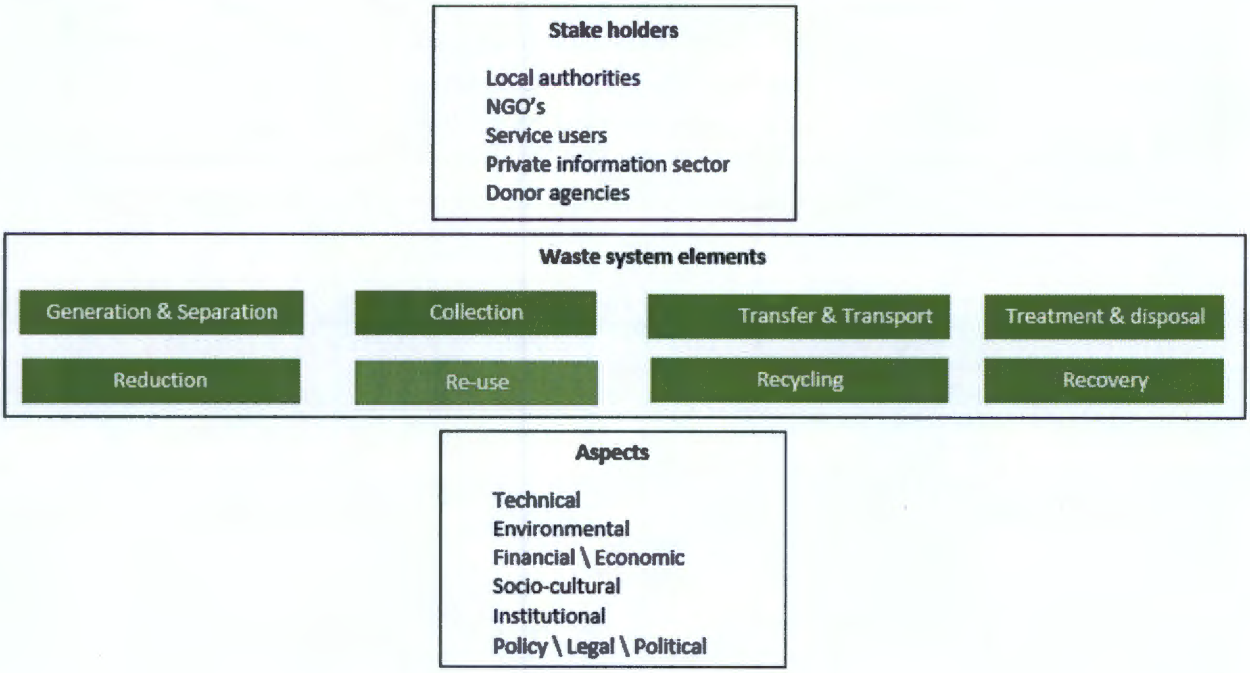


Figure 5: Integrated Waste Management System dimensions
(adapted from Mannie and Bowers, 2014)

2.1.6. Waste management systems in developed countries

In the past twenty years, developed countries have made remarkable achievements in adopting the waste hierarchy. Comparing Sakai et al. (1996), presented in table 2 and data retrieved from Eurostat (2009), presented in figure 6 - shows that the amount of waste landfilled was reduced by about 43%, 50% and 54% in the Netherland, Germany and Sweden respectively.

Both studies (Sakai et al, 1996 and Eurostat, 2009) also reveal a relatively high percentage of waste incineration in developed countries, this can be attributed to the dry and high calorific nature of waste in developed countries (US EPA, 2002; Thomas, 2006; Mohee, 2002). Japan for example, has an exceptionally high waste incineration percentage of 74%, compared with Canada's 14%, and this can be attributed to the limited land availability in Japan and the high volume reduction of up to 90% that incineration technology allows (Sakai et al, 1996).

Though ranked at the top of the waste hierarchy, waste avoidance and minimization can only target a fraction of the waste and further waste management initiatives are required. Though incineration allows a significant waste volume reduction, the higher priority of reuse and recycling in the waste management hierarchy as well as the significant amounts of biodegradable organic fraction of waste, has pushed developed countries towards composting and anaerobic digestion (AD). The desire for high quality compost has driven developed countries to roll out waste separation at source initiatives (Sakai et al, 1996).

Waste separation at source, is typically done by encouraging people to separate their waste into a dry and wet fraction. The dry fraction can be sorted into recyclables more easily and the wet fraction can be processed into a high quality or less contaminated compost more easily than with the case of mixed waste. Experience from several European countries has shown that up to 70% of the organic fraction of MSW (OFMSW) can be captured in the wet fraction for the production of high quality compost. The alternative to separation at source is mechanical separation and sorting plants, where the waste is separated and sorted into its different fractions with machines and manual sorting (Braber, 1995).

Country	Canada	Denmark	Germany	Netherland	Sweden	USA	Japan
Area (Km^2)	9,980,000	43,000	357,000	42,000	450,000	9,160,000	378,000
1995 Population (x10^6)	29	5.2	82	15	8.9	263	125
1994 GDP (billion US $)	548	96	1,467	263	154	6,736	1,630
1993 MSW quantity (million tons)	33.76	2.3	43.5	12	12	207	5.2
Management method (%)	Composting 1.83% Incineration and recycling 14.22% Landfill 83.9%	Recycling 22% Incineration with energy recovery 58%	Sorting and recovery 30% Incineration 25% Landfill 45%	Recycling 22% Incineration 27% Landfill 61%	Recycling 18% Composting 2% Incineration 53% Landfill 27%	Recycling and composting 22% Incineration 16% Landfill 62%	Recycling and composting 10.8% Incineration 74.3% Landfill 14.9%

		Landfill 20%					
MSW composition (weight basis %)	Paper 37.7 Organic 28.8 Metal 10.4 Glass 4.4 Inorganic 0.9 Other 9.4		Paper 19.9 Textile 1.5 Plastic 6.1 Metal 3.9 Glass 11.5 Minerals 2.9 Putrescible 27 Middle fraction 15.6 Fine fraction 8.6 Others 3.1	Putrescible 30 Plastic 4.2 Metal 1 Glass 3.4 Bulk 5.6 Office waste 14.1 Paper\cardboard 17.1 Packaging 15.6	Paper 35-40 Wood 1 Textile, rubber, leather 1-2 Food, yard trimming 37-45 Plastic 6-8 Glass 4-7 Metal 2-5 Others 4-6	Paper 37.6 Glass 6.6 Metal 8.3 Plastic 9.3 Wood 6.6 Food 6.7 Yard trimming 15.9 Others 9	Organic 42.3 Paper 25 Plastic 11.2 Textile 5.5 Glass 2.9 Metal 5.1 Rubber and leather 0.9 Other 7.1

Table 2: Overview of the MSW and main treatment options in seven developed countries (adapted from Sakai et al., 1996)

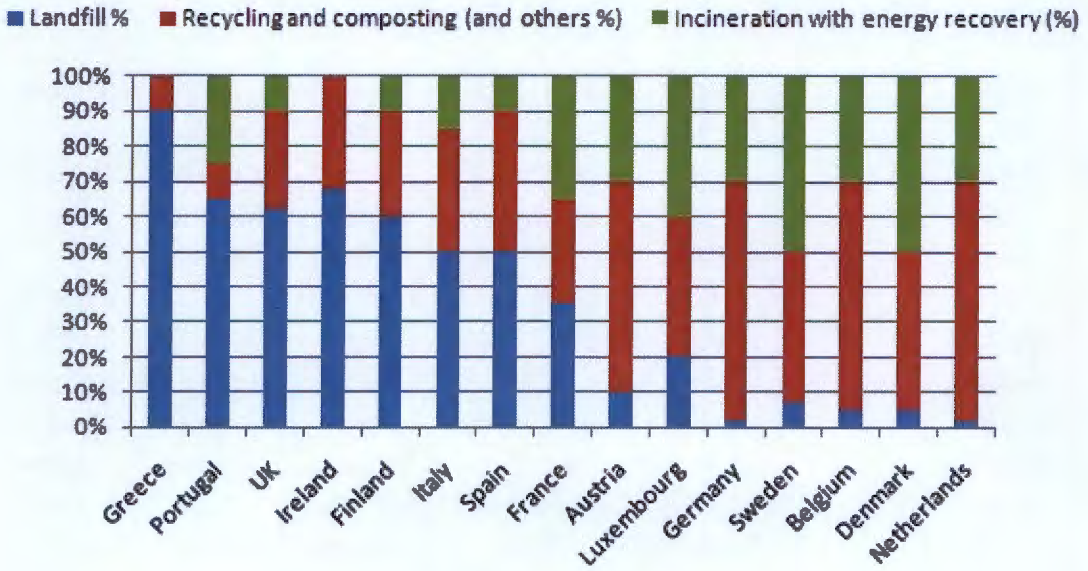


Figure 6: MSW management in the European Union in 2006
(Adapted from Eurostat, 2009)

2.1.7. Waste management systems in South Africa

The end of apartheid in South Africa in 1994 and the advent of democracy, has led to an increased demand for adequate public services including waste management (Gilbert, et al., 2014). Waste Management is a challenge in most municipalities in South Africa. This is a growing trend and continuous to be an issue for the Public and Municipal Officials. The Department of Environmental Affairs and Tourism (2007) reported that 87% of municipalities lack capacity and infrastructure to properly implemented waste minimization strategies. It is estimated that in 2007, 95% of household waste was directed to landfills according to the Department of Environment affairs (DEA, 2007).

South Africa has a comprehensive legislative framework for waste management, this framework includes but not limited to:

- National Environmental Management Waste Act (Act 59 of 2008) (NEMWA).
- SECTION 156(1) (a) of the Constitution, read with Schedule 5, assigns responsibility for refuse removal, refuse dumps, solid waste disposal and cleansing to the local governments.
- Objectives are designed within the context of municipal government strategies as set out in section 152(1) of the Constitution referring to the objective "To promote a safe and healthy environment" including the Principles of NEMWA and the Bill of Rights as stated in the Constitution.
- The Municipal Systems Act 2000 (Act 32 of 2000) describes the core principles, mechanisms, and processes that are necessary to enable municipalities to move progressively towards the social and economic upliftment of communities and ensure access to services that are affordable to all. Its focus is primarily on the internal systems and administration of the municipality.
- Legislation such as NWMS -The National Domestic Waste Collection Standards and the Municipal Waste Sector Plan (MWSP) are crucial instruments of waste legislation that provide

overall guidance to effective waste management and as such disposal and infrastructure are inherent parts of this.

- The Polokwane Declaration signed during the first South African Waste Summit in 2001 has set new standards towards "reduction of waste generation and disposal by 50% and 25 % respectively by 2012 and the development of a 'zero waste' plan by 2022".
- Solid waste disposal in South Africa is regulated by the minimum requirements for disposal of waste by landfill, published by the department of water affairs and forestry (DWAF, 1998).

2.1.7.1. Challenges

Poor interpretation and understanding by municipal officials of the legislative policies, guidelines, frameworks and agreements is a weakness in waste management policy implementation in South Africa. The lack of training in this area is impeding the implementation of the correct waste solutions. Often the capacity and knowledge base required for future development is not adequately considered (Mannie and Bowers, 2014).

There is failure to understand the regulations and legislative framework on waste management at national, provincial and local level. The individuals tasked with the waste management responsibility do not have the depth or clear understanding to implement the legislation as required. This limitation impacts on the correct waste disposal solution being considered (Mannie, N.M. and Bowers, A., 2014).

As the authorities pursue implementation and the prescriptions of the Waste Act and the associated legislative requirements and frameworks, one of the key challenges that is currently arising is determining the right choice of disposal or waste management solution at a Municipal level whether it is local or District level. Due to the historical waste management system and legislation focus on the "concentrate and contain", it is almost assumed and practiced that landfills are the ultimate solution for disposal in local municipalities (Munganga, 2011). However, due to the vast expanse of the rural local municipalities, landfills are not the most ideal solution anymore. This is largely attributed to the low population and low density nature of these towns which implies large distances to travel for waste collection and landfilling. Extremely low-income levels which characterize rural settlements also brings the challenge of recovering waste management cost with tax and levies (Mannie and Bowers, 2014).

Most municipalities within the South Africa do not have waste information systems and infrastructure in place to accurately measure waste disposed or diverted from landfills within their municipal boundaries. The collection and analysis of accurate and reliable waste data is a key requirement to inform the development of Integrated Waste Management Plans (IWMP). It assists municipalities to set baselines from where short, medium and long term integrated waste management targets can be set and helps the municipality to design and implement a more efficient and effective integrated waste management system (Gilbert et al., 2014; Mannie and Bowers, 2014).

Rising costs, limited revenue and seeking an alternative "fit for purpose" solution continuous to challenge municipalities on rendering an effective waste service. Another key problem in municipalities is the illegal development (historically) of open dumps now termed "landfills" which have not been properly managed and have contributed to the rise of health and safety issues, contamination of the underground water systems and sources. The required levels of conforming to legislation and the escalating costs of operating and building new landfills further compounds the problem (Kristiansen T., 2014; Mannie, N.M. and Bowers, A., 2014).

Some of the challenges facing municipalities include:

- No waste planning-Past and future trends and dynamics are not considered.
- Poor waste management knowledge, understanding waste in the larger context, lack of training, institutional and technical ability.
- No waste management capacity in the municipal management team to direct and take ownership of decisions, often this service area is absent or incorporated into other service areas.
- Financial constraints, no access to adequate funding from National Treasury, Grants or donor funding.
- Poor financial planning by the municipal officials often lead to waste infrastructure initiatives not being planned for in the right period or at all, not seen as a priority.
- Poor formulation of waste management strategies. Limited solutions explored forcing clients to use traditional approaches.
- Failure to apply "back to basics" approach as the decision makers have not acknowledged that simple cost effective solutions are what is required to close the waste disposal challenges in local municipalities;
- Promoting cost efficiencies is over looked. Emphasis in this area could greatly improve operational and delivery objectives.
- Health, safety and environmental challenges are not sufficiently addressed in the waste disposal solutions. Litter and scavenging on landfills in the local municipalities is an enormous challenge as well as an exceptional risk thereby compromising operations, livelihoods of scavengers and a safe environment (Mannie and Bowers, 2014).

Research by Matete and Toris (2008) shows that many local municipalities in South Africa have been adopting the 3R principle, meaning Reduce, Reuse and Recover through municipal bylaws, since 2000, in order to reach sustainability goals. The 3R principle is a type of waste hierarchy from which waste minimization and zero waste emerged as legitimate and practical tools (Matete and Toris, 2008).

Matete and Toris (2008) also developed a model evaluating different strategies to attain waste minimization and zero waste and applied the model on Durban municipality as a case study. The model results prioritized the following strategies: waste minimization at manufacturing, waste minimization at point of purchase, waste reuse in the household level and wet\dry waste separation system at the point of collection, for a more efficient recovery and recycling of the remaining waste.

Further research by Matete and Toris (2008), focusing on the last step mentioned above – dry\wet separation at point of collection, argues that the leading criteria for selecting the optimal method and technology for waste processing and treatment in South Africa should be: low energy demand, labour intensity (for job creation), low capital and operational costs and applicability to existing landfill operation. The results of their research, marked dome aerated technology for compost production as the preferred technology and method. However in practice, the success of the technology was very limited mainly because of the poor quality of substrate, which was mainly a result of poor separation at source and the lack of suitable off-take for the compost (Matete and Toris, 2008).

In 2007 the city of Cape Town implemented a pilot project called Think Twice. The project is a campaign, implemented in certain areas of Cape Town Municipality, for waste separation at the household level. Residents are encouraged to separate their waste using the dry\wet system. The wet fraction, containing food and garden waste is collected separately, a small portion of it is sent to composting while the majority is landfilled. The dry fraction containing recyclables, is collected separately and sent to a material recovery facility (MRF) for recycling (City of Cape Town, 2011).

The literature review conducted for this study didn't find any evidence of utilizing anaerobic digestion (AD) technology for MSW treatment, using energy recovery and compost production in South Africa. Palczynski (2002) argues that given the nature of MSW in developing countries, AD should be the focal point for the OFMSW, of the integrated waste management systems (Palczynski, 2002).

2.1.8. MSW to energy

MSW to a large extent, is made of energy rich materials, such as OFMSW, which can be used as an alternative energy source to conventional fossil fuels. Other types of waste such as animal waste, agricultural waste and some industrial wastes can also be used for renewable energy generation (Deublein & Steinhauser, 2011).

There are many waste to energy technologies and these can be categorized into four main technology types: Thermal, biological, physical and chemical. Figure 7 below shows the main waste to energy technologies categories.

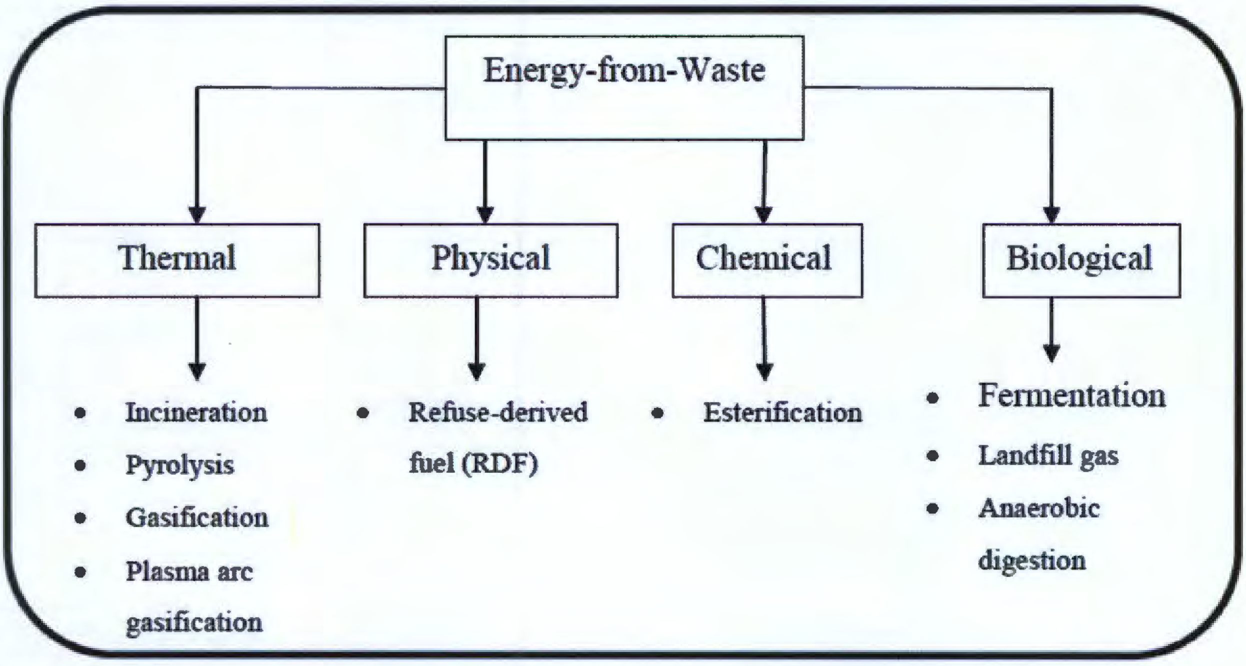


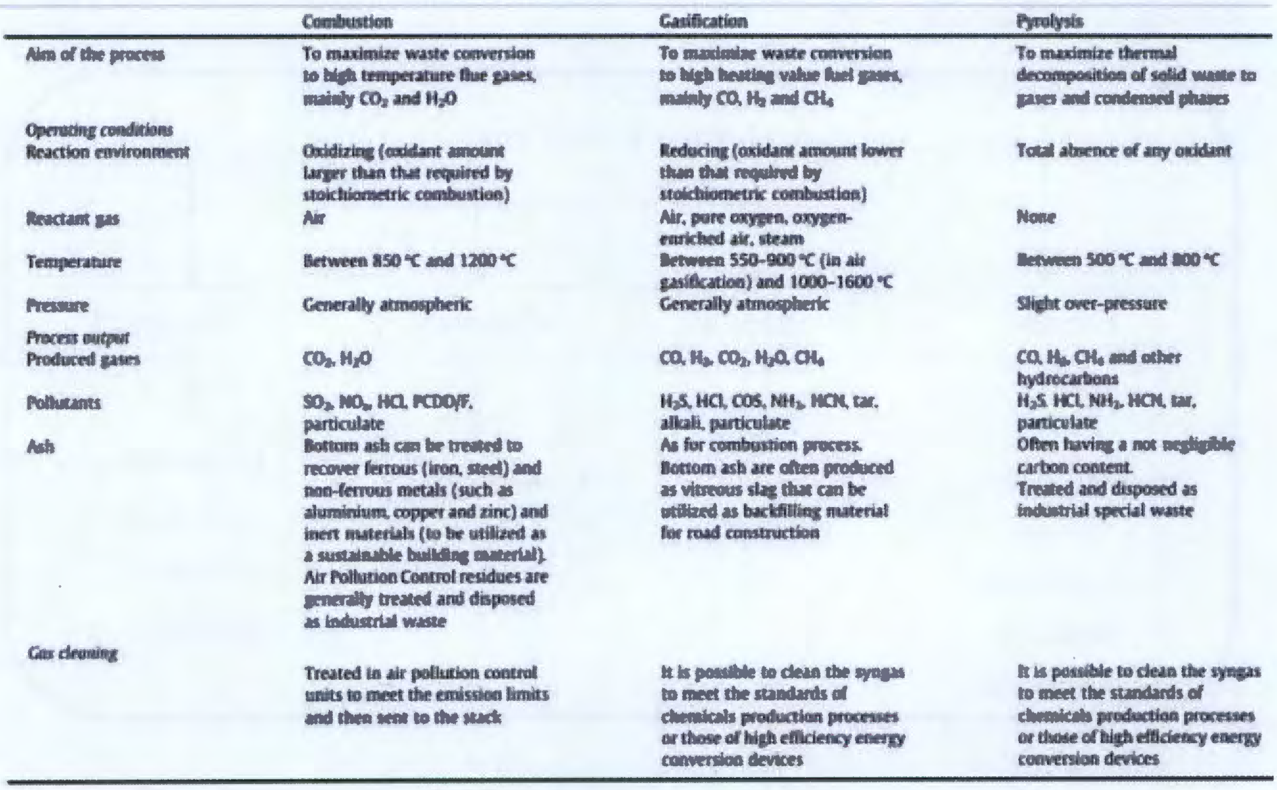
Figure 7: Waste to energy technologies
(adopted from Luxresearch, 2007; Wagner, 2007)

Physical processing is a preliminary step for waste to energy production, it involves mechanical and physical separation of waste to desirable sub-components, such as refuse derived fuel (RDF) for further thermal processing and OFSM extraction for further biological or chemical processing. Recyclables such as metal and glass can also be extracted for reuse (Luxresearch, 2007).

Chemical processing of waste is typically limited to waste oil, which can be found in restaurants for example. The chemical treatment of oil or esterification is used to convert the oil into a biofuel, like biodiesel. This process is also applicable to oil producing energy crops such as Jatropha (Wagner, 2007).

Thermal treatment of waste and MSW, and especially direct combustion, has established a relevant and even necessary aspect of any IWMS. Many studies and analysis backed up by successful international experience has proven thermal MSW treatment as an important waste to energy technology (Psomopoulos et al., 2009; Umberto, 2012).

Thermal treatment of MSW is often accompanied with renewable energy generation. Heat is produced, typically in the form of steam, and is used for electricity generation, district and\or process heating. Other possible energy products are fuels in the form of gas (commonly known as syngas) or liquid. Thermal processing technologies can be divided into three main categories: Pyrolysis which is aimed towards producing liquid fuels, gasification which is aimed towards producing gas fuels and direct combustion which is aimed to produce heat energy (Umberto, 2012; Thomas, 2006; Mohee, 2002). The table below explains and summarizes key parameters of each process:



	Combustion	Gasification	Pyrolysis
Aim of the process	To maximize waste conversion to high temperature flue gases, mainly CO_2 and H_2O	To maximize waste conversion to high heating value fuel gases, mainly CO, H_2 and CH_4	To maximize thermal decomposition of solid waste to gases and condensed phases
Operating conditions			
Reaction environment	Oxidizing (oxidant amount larger than that required by stoichiometric combustion)	Reducing (oxidant amount lower than that required by stoichiometric combustion)	Total absence of any oxidant
Reactant gas	Air	Air, pure oxygen, oxygen-enriched air, steam	None
Temperature	Between 850 °C and 1200 °C	Between 550–900 °C (in air gasification) and 1000–1600 °C	Between 500 °C and 800 °C
Pressure	Generally atmospheric	Generally atmospheric	Slight over-pressure
Process output			
Produced gases	CO_2, H_2O	CO, H_2, CO_2, H_2O, CH_4	CO, H_2, CH_4 and other hydrocarbons
Pollutants	SO_2, NO_x, HCl, PCDD/F, particulate	H_2S, HCl, COS, NH_3, HCN, tar, alkali, particulate	H_2S, HCl, NH_3, HCN, tar, particulate
Ash	Bottom ash can be treated to recover ferrous (iron, steel) and non-ferrous metals (such as aluminium, copper and zinc) and inert materials (to be utilized as a sustainable building material). Air Pollution Control residues are generally treated and disposed as industrial waste	As for combustion process. Bottom ash are often produced as vitreous slag that can be utilized as backfilling material for road construction	Often having a not negligible carbon content. Treated and disposed as industrial special waste
Gas cleaning	Treated in air pollution control units to meet the emission limits and then sent to the stack	It is possible to clean the syngas to meet the standards of chemicals production processes or those of high efficiency energy conversion devices	It is possible to clean the syngas to meet the standards of chemicals production processes or those of high efficiency energy conversion devices

Table 3: Main characteristics of the chemical processes for thermal treatment of solid waste (Adapted from Arena and Mastellone, 2010)

In developed countries, thermal processing of MSW and direct combustion especially is one of the more common MSW treatment processes. Limited land space and high land costs combined with the high calorific value of MSW, are two of the key drivers for thermal processing being a preferred and common method of choice in developed countries. In developed countries, most of the thermal processing plants of MSW are accompanied with renewable energy generation in the form of heat or electricity (Thomas, 2006; Mohee, 2002). Increasing rigidity and enforcement of environmental regulation is another key driver to the wide spread of thermal processing of MSW and at the same time, one of its main obstacles, since it is associated with high capital costs, for example flue gas and ash treatment and disposal attract high capital and operational costs (Sakai et al,. 1996).

Rand et al. (2000) also raised the point of high costs associated with thermal processing of MSW: "scrubbers for post-treatment of the flue gas, and adequate disposal of the ash generated have become mandatory for incineration facilities due to stringent environmental regulations". They then further argue that despite its clear advantages, thermal processing of MSW is generally considered not suitable for developing countries (Rand et al., 2000) due to lack of suitable infrastructure, supporting industries, availability of spare parts and expertise, as well as high capital and operational costs (Zerbock, 2003). This is further supported by SEA & AMATHEMBA (2007) who claim that incineration technologies are uneconomical compared with typical current waste management methods, due to the high capital and operational costs associated with the treatment of toxic fumes and hazardous ash, produced as a result of thermal processing of MSW.

Biological treatment of MSW includes fermentation, landfill gas extraction and AD. Fermentation is a biological process where simple organic sugars are converted to ethanol which can be used as renewable fuel. In landfill gas extraction, the landfill gas, which is generated through the natural decomposition of the OFMSW, is extracted, treated (cleaned) and used as a renewable energy source for electricity generation or heating (Wagner, 2007). AD will be discussed in more details in section 2.3.

One of the first and few biological waste to energy technologies implemented in South Africa is the landfill gas extraction project in the city of Durban, where the landfill gas is utilized for electricity generation used by the city (CoD, 2009). Although landfill gas extraction projects generated renewable energy and reduce GHG emissions, however, unlike AD, they lack the added advantage of diverting waste from landfills.

Composting is another type of biological waste treatment, it involves aerobic treatment of the OFMSW for compost production but doesn't include renewable energy generation. Composting of OFMSW has been the preferred method of choice and more common than AD, mainly due to its relatively lower capital and operational costs. However composting is a net energy user where AD is a net energy exporter. Composting requires 50-75 kWh per ton of MSW where AD generates 75-150 kWh (Braber, 1995). In light of increasing energy costs and low energy security, AD is becoming more preferable than composting (Sakai et al., 1996, Braber et al., 1995). This claim is further supported by the UNEP (2002) that claimed that composting will be optimized if priory subjected to AD for renewable energy generation (UNEP, 2002).

2.2. Energy in South Africa and Cape Town

South Africa has an installed electricity generating capacity of about 45 GW and consumes about 255 TWh (as of 2014). Its peak demand is estimated at around 35 GW. South Africa generates about two-thirds of Africa's total electricity supply and is one of the cheapest electricity producers in the world. 93% of South Africa's installed electrical capacity is sourced from coal and centralized around the coal mining area – Mpumalanga. Eskom, the state owned utility provider supplies about 90% of South Africa's electricity (BP, 2013; Eskom 2014).

South Africa imports most of it fossil fuels and consumed about 800 PJ of fossil fuel energy in 2010. South Africa's fossil fuel consumption is mainly used by its transportation sector (Merven et al, 2012).

South Africa is the largest emitter of GHG in Africa, contributing over 40% of Africa's total CO2 emissions. In 2009 South Africa emitted 511 million to of CO2 equivalent GHG, 85% of which is attributed to the energy sector (IEIA, 2009).

Recent load shedding and Eskom's poor financial state are few of South Africa's energy problems including but not limited to: energy security, energy poverty, negative environment impact, energy cost, etc. (Creamer Media, 2014).

Cape Town is heavily reliant on the national utility provider Eskom for its electricity supply (SEA, 2007). It is estimated that 95% of Cape Town's electricity comes from Eskom's coal fired power stations in the north of the country while only 5% are provided from Cape Town's nuclear power station Koeberg (SEA & AMATHEMBA, 2007). This situation presents an environmental problem, due to the long electricity transmission distance and the associated transmission loses (Winkler et al., 2005).

Figure 8 below shows Cape Town's energy source mix.

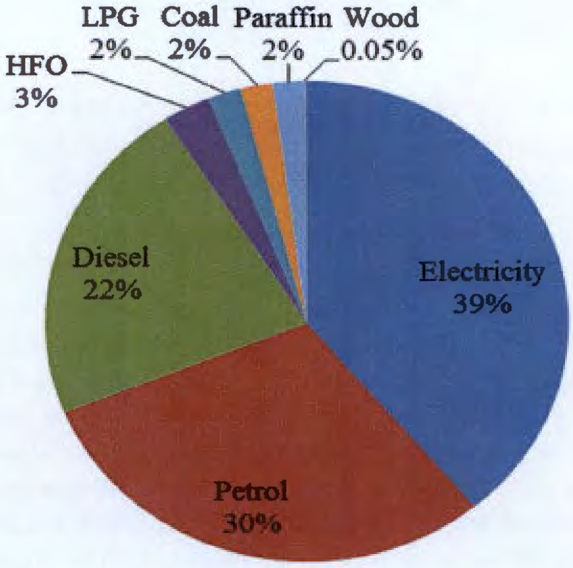


Figure 8: Cape Town's energy source mix in 2007 (adopted from SEA & ERC, 2010)

It can be witnessed from figure 8, that Cape Town's main energy source is electricity and that Cape Town is heavily reliant on conventional fossil fuels. Ward & Walsh (2010) calculated that in 2006, Cape Town's electricity demand generated 21.1 million tons of carbon dioxide equivalent, considering that Cape Town's population at that time was estimated to be 3.4 million people, this equates to 6.2 tons per year per capita of carbon dioxide equivalent emissions (Ward & Walsh, 2010).

2.3. Anaerobic digestion

2.3.1. Background

Anaerobic digestion (AD) is a well-established technology. Industrial applications of AD date back to 1895, for sewage treatment in England (Lettinga, 1996). The AD process occurs naturally in organic matter, the natural and artificial AD process has been utilized for many uses, most commonly to stabilize waste water sludge (Janssen, 2010). Artificial AD process takes place in a digester or reactor (Wilkie et al., 2008). AD can be broken down into four main phases that occurs in the following order: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Deublein & Steinhauser, 2011).

Early designs of AD plants aimed at OFMSW emerged in Europa in the early 1990's (Karagiannidis and Perkoulidis, 2009). AD of agricultural and kitchen waste is very common in China and India, mainly for cooking and lighting applications (Feng et al., 2009; Bhatia, 1990). Experience from China and India demonstrate the potential of AD for decentralized application suitable for other developing countries, especially in Africa. As explained in section 2.1.7., landfilling of MSW without prior treatment is the most common practice in Africa. Considering the challenges of energy poverty and security, AD of MSW accompanied with renewable energy recovery may be an ideal solution for addressing both waste management and energy supply (Greben et al., 2009).

The process of AD is the biodegradation of organic materials, in the absence of oxygen, by anaerobic bacteria. The results of the process are methane rich biogas (typically 50-70%) and sludge.
Methane has a high calorific value and is commonly mined as natural gas as an energy carrier, therefore the biogas can be used as a renewable energy source, the sludge has a high nitrogen, carbon and other plant nutrition values and can be used as an organic fertilizer (Ahring, 2003).

The high organic content of MSW in developing countries, the need to treat and divert MSW from landfill, the ability to recover renewable energy and the suitability of AD to decentralized applications, mainly thanks to its flexibility and simplicity, positions AD as an important technology for organic waste treatment in developing countries (UNEP, 2002; Ponsa et al., 2008). This is further supported by Palczynski (2002), who argues that waste management systems in developing countries should integrate AD (as well as reduction, reuse and recycling of waste) as a method of choice for the OFMSW and only the residual fraction of the MSW may be landfilled (Palczynski, 2002).

In South Africa, AD technology can be found in part of the country's waste-water treatment plants to treat and reduce the amount of sludge. Most of the AD plants in South Africa are over designed, not properly operated, and the biogas is often ventilated or in the better cases flared (Snyman et al., 2006; Ross et al., 1992). Therefore a cost effective implementation of AD can be achieved by utilizing the existing digesters in operation in waste-water treatment plants. This has been successfully demonstrated in Russia. A lab experiment tested the co-digestion of waste water sludge with kitchen waste to demonstrate the feasibility of the concept, the test reported that highest biogas yield was witnessed at a ratio of 70% and 30% of waste water sludge and kitchen waste respectively (Greben et al., 2009).

2.3.2. Types of anaerobic digestion systems

The main types of anaerobic digestion systems are: single or multi stage, dry or wet, mesophilic or thermophilic and batch, semi batch or continuous. Choosing the digester type is typically a function of budget, application, available space, size\throughput\organic loading rate, type of feedstock and its characteristics such as total solids, volatile solids, carbon to nitrogen ratio, etc. (Chynoweth et al., 2001). AD reactors can be found in various sizes and geometries, vertical or horizontal (Karagiannidis and Perkoulidis, 2009).

One of the more important parameters in AD the type of AD systems is the retention time or the digestion period. Hydraulic retention time and solid retention time, which will be described in more details in section 2.3.4.9., are sometimes separately referred to since the solid retention time is much more relevant for biogas production. As an example, in industrial OFMSW applications, the typical average retention time is 25-30 days, with a respective 56% mass waste reduction and a biogas yield of about 570 liter biogas, per one kg of dry solids (with 55% methane) (Ponsa et al., 2008).

In continuous AD systems the feedstock is loaded and removed from the digester continuously, meaning volumes of fresh feedstock equal discharged digestate (Buekens, 2005; Verma, 2002). In a batch system the digester is fed once until it's filled, the retention time is completed and the digester is emptied, then the process is repeated (Chaudhary, 2008). In both systems it's typical to reuse 10%-15% of the digestate in order to maintain the bacteria culture (Igoni et al., 2008). Batch digesters are much simpler to operate (Klass, 1998). However batch digesters are more inclined to process inhibition and even failure, since shifts in the AD bacteria population are very difficult and even impossible to balance (Klass, 1998). One of the most common continuous AD systems is the complete stirred tank reactor (CSTR), they are most common at WWTP (Waste Water Treatment Plant) and for high TS feedstock (Klass, 1998; Karellas et al., 2010).

Dry and wet AD systems differs by the moisture content of the substrate in the digester where wet systems typically operate at 90-85% moisture content versus 75-60% of dry systems. In wet systems water is added to the substrate to increase the moisture content or preferably high moisture feedstock such as municipal waste water is co-digested (Chaudhary, 2008; Karagiannidis and Perkoulidis, 2009). The advantages of a wet system compared with dry system are higher biogas yield and better process control, where the disadvantages are higher capital cost, higher operational cost associated with higher energy demand for mixing and heating, higher water demand (not in cases of co-digestion), bigger land requirement and higher effluent production. However it is important to note that the disadvantages of a wet system compared with a dry system are often compensated by the higher biogas yield (Forster-Carneiro et al. 2008). Recirculation of bacteria seed culture is typically done in wet systems by pumping back to the digester a fraction of the effluent and in dry systems by collecting leachate from the bottom and spraying it on top (Luning et al., 2003)

Single stage and multi stage AD systems differs by the amount of dedicated and separated reactors for the different biological process that forms the AD process and their associated bacteria cultures. A single stage AD system has one reactor, its advantages are lower capital and operational costs, lower footprint, easier to operate (compared with multi stage systems) and higher up time\availability (Forster-Carneiro, Perez, and Romero, 2008; Luning et al., 2003). In multi stage AD systems, the AD process is typically separated into two stages (or more), in two different reactors, where the first reactor accommodates the hydrolysis, acidogenis and acetogenis bacteria and processes, and the second reactor accommodates the methanogens bacteria and process, feeding from the volatile fatty acids generated in the first stage. It is important to note that a complete separation of the stages cannot be achieved since traces of the bacteria and process of all stages will always be found in all stages (Karagiannidis and Perkoulidis, 2009; Fannin et al., 1987). The main advantage of multi stage AD systems (over single stage systems) is a higher biogas yield, resulting from avoidance of over accumulation of volatile fatty acids which interferes with the methanogens bacteria work. Single stage AD systems are much more common than multi stage AD systems, despite their theoretical higher biogas yield, since in practice single stage systems are cheaper and easier to operate and therefore often results in higher biogas yield (Appels et al., 2008; Igoni et al., 2008).

Mesophilic and thermophilic AD systems differs from each other by the operating temperature of the AD reactor, which determines the type of methanogens bacteria dominating the process. Mesophilic AD systems operate at 30-38°C whereas thermophilic AD systems operate at 49-57 °C. Mesophilic AD systems are more common to find mainly since they have lower capital and operational cost, easier to operate and less sensitive to process variations (such as change in temperature, PH level etc.). The main advantage of thermophilic AD systems is higher biogas yield and higher pathogens destruction (YC Song et al., 2004).

2.3.3. Microbial processes in anaerobic digestion

The anaerobic digestion process is made of four stages which are driven by four main groups of bacteria. The first stage of anaerobic digestion is hydrolysis, in this stage insoluble organic complex matter is broken down to smaller soluble monomers. The second stage is acidogenesis, in this stage the monomers from the hydrolysis stage are converted to organic acids. The third stage is acetogenesis, in this stage the organic acids from the acidogenesis stage are converted to acetate, hydrogen and carbon dioxide. The final forth stage is methanogenesis, in this stage the acetate (mainly) from the acetogenesis stage is converted to methane and carbon dioxide (Lyberatos and Skiadas, 1999). Figures 9 below illustrate the microbial AD process.

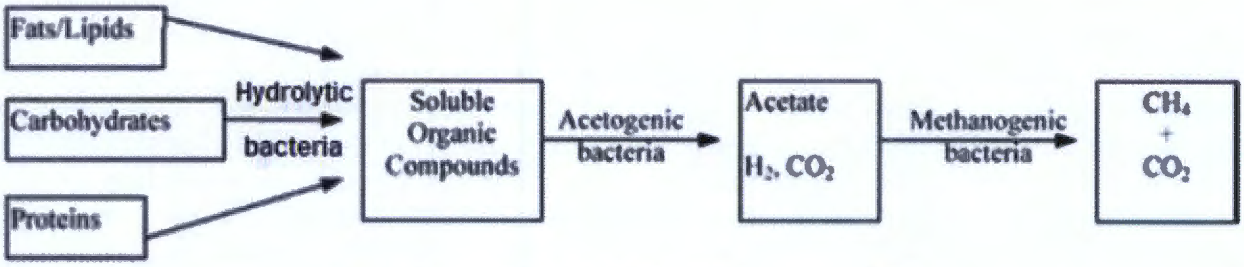


Figure 9: The different biochemical process of AD
(adapted from Lyberatos and Skiadas, 1999)

2.3.3.1. Hydrolytic bacteria

The hydrolysis stage is the first stage of anaerobic digestion, which produces the substrate for the following stages, therefore it determines the rate of the anaerobic digestion process. In the hydrolysis stage hydrolytic bacteria transforms insoluble complex organic substrate such as proteins, fat and complex carbons such as cellulose, hemicellulose, lignin and starch, into soluble monomers such as amino acid, fatty acid and glucose (Chynoweth and David Pl., 1987). The rate of the hydrolysis phase is mainly a function of the digested substrate characteristics i.e. the physical and chemical structure. Small and simple molecules like sugars, which are common in food waste will break down faster in the hydrolysis stage than larger and more complex molecules like cellulose, hemicellulose and lignin, which are more common in garden and green waste (Chynoweth and David Pl., 1987; Ward et al., 2008). The hydrolysis of carbohydrates occurs within few hours, protein and fats within few days and cellulose, hemicellulose and lignin within few weeks where often the biodegradation is not complete (Deublein & Steinhauser, 2011).

2.3.3.2. Acidogenic and acetogenic bacteria

In the acidogenic phase, acidogenic bacteria synthesises the fatty acids, amino acids and glucose (monomers) resulting from the previous hydrolysis phase, into caproate, valeric, butyric, propionic and acetic acids, which are organic soluble acids with a C2 to C6 chain lengths. In the acetogenesis phase, the products of the acidogenic phase – the organic soluble acids are synthesized by acetogenic bacteria into acetate, carbon dioxide and hydrogen (Wang et al., 1999). Equations 1 and 2 below, demonstrate the acidogenic and acetogenic process respectively (Chynoweth and David Pl., 1987)

$$Sugars \rightarrow CH_3CH_2COOH + 2H_2O$$

Equation 1

$$Amino.Acids \rightarrow Alcohols/\ L.Acid/\ F.Acids$$

Equation 2

2.3.3.3. Methanogenic archaea

Archaea are amongst the oldest types of bacteria known. Methanogenic archaea synthesises organic acids into methane, carbon dioxide and water, in nature they can be typically found in Ruminant's stomachs, there are about 33 types of Methanogenic archaea known to date and they vary in accordance to their environment and the substrate they digest. There are two groups of Methanogens: methylotrophic and non-methylotrophic. Methylotrophic methanogens use methylated amines, methanol and acetate while the non-methylotrophic digest formate, carbon dioxide and hydrogen, equations 3 and 4 below describe the methanogenic process (Chynoweth and David P., 1987). In general, about 72% of the methane in biogas originates from acetate while the remains is formed from formate hydrogen and carbon dioxide. Methanogenic archaea growth is stimulated by certain vitamins, minerals and fatty acids. Methanogenic archaea are sensitive to acidic conditions, therefore It is important to note that though the Methanogenic archaea are dependent on the hydrolysis, acidogenic and acetogenic bacteria to generate the substrate from which they feed but too much substrate may result in increase in the PH level and decrease in the methanogenic archaea activity and the resulting biogas production (Chynoweth and David P., 1987; Chen et al., 2008; Deublein & Steinhauser, 2011).

$$CH_3COOH \rightarrow CH_4 + CO_2$$ Equation 3

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$ Equation 4

The first three phases of the AD process are much faster compared with the last Methanogenic phase, due to the relatively slower growth rate of Methanogenic archaea. The regeneration rate of Methanogenic archaea is 5-16 days while acidogenesis and acetogenesis bacteria's growth rate is about 24 hours and 90 hours respectively. This explains the biogas production peaks, often observed in the first few days of AD, attributed to the production of hydrogen and carbon dioxide by the hydrolytic acidogenytic and acetogenytic bacteria, prior to the Methanogenic archaea culture stabilization and resulting methane rich biogas production (Deublein and Steinhauser, 2011).

2.3.4. Important parameters in anaerobic digestion

The main purpose of artificial AD systems is methane production for energy applications and waste stabilization, the main driver of both is a sustainable population of the various bacteria involved and its symbiotic AD biochemical reaction. For that aim there are several process parameters that are essential to monitor and control: waste composition and size, temperature, PH and mixing. This is discussed below.

2.3.4.1. Waste composition (carbon-to-nitrogen ratio)

A sustainable population of the various AD bacteria and its respective symbiotic operation requires energy and food for the bacteria. The AD waste\feedstock composition should provide that in a balanced manner. Carbon to nitrogen ratio (C:N) is a good and useful indicator for the bacteria's diet where carbon and nitrogen are the sources of energy and food (amino acids) respectively (Salminen and Rintala, 2002). Resch et al. (2011) suggest using chemical oxygen demand (COD) to total Khedjal Nitrogen (TKN) ratio as an alternative indicator to the suitability of the feedstock composition to the AD process.

Control of the (C:N) ratio can be done by mixing different waste streams. For example, energy crops, food waste and OFMSW are rich in carbon, while chicken manure, slaughter house waste and raw sewage are rich with Nitrogen (Sosnowski et al., 2003; Gomez et al., 2006; Cuetos et al., 2008; Luste et al., 2010). Mixing of different feedstocks or co-digestion has been a common practice for many years. For example, nitrogen rich and low biogas yielding feedstocks such as slaughter house waste and sewage sludge, are often co-digested with carbon rich feedstocks to improve the biogas yield (Kayhanian, 1999; Igoni et al., 2008, Rosenwinkel and Meyer, 1999; Salminen et al., 2003). Mata-Alvarez et al. (2000) explain the benefits of co-digestion and the resulting balanced (C:N) ratio to be dilution of inhibitive substances, increase in nutrients and better overall digestion process performance resulting from synergetic effects between the different feedstocks (Mata-Alvarez et al., 2000).

An unbalanced (C:N) ratio will lead to a decrease in the different bacteria population, harm their symbiotic relations and will result in less effective waste degradation and lower methane yield. Over supply of carbon or high (C:N) ratio leads to excess of degradable material, fast consumption of nitrogen and slows down the degradation process, while oversupply of nitrogen or low (C:N) ratio leads to conversion of the oversupply to ammonia (NH3) resulting in ammonia inhibition of the AD process (Bernal et al., 2009; Deublein & Steinhauser, 2011).

Resh et al. (2011) argues that carbon is consumed 30-35 times faster than nitrogen, therefore he proposes that the ideal (C:N) ration should be 16-25 (carbon to one nitrogen). This is further supported by Parkin & Owen (1986) as well as Monnet (2003) who suggested that the ideal (C:N) ratio should be 30-35 (Monnet 2003; Resch et al., 2011; Parkin & Owen, 1986).

Table 4 below, shows the (C:N) ratios of different common types of AD feedstock, from different literature sources.

Feedstock	**(C:N) ratio**	**Source**
Abattoir waste	3.7	Cuetos et al., 2008
Energy crop – straw	90	Deublein & Steinhauser, 2011
Paper waste	125.5 / 201	Myréen et al., 2010 / Munganga et al., 2010
Primary sludge	6-9	Deublein & Steinhauser, 2011
Household waste	18-28	Deublein & Steinhauser, 2011

Table 4: (C:N) ratio of common AD feedstock
(adapted from Cuetos et al., 2008; Deublein & Steinhauser, 2011; Myréen et al., 2010; Munganga et al., 2010)

It can be witnessed from the table above that household waste is within the recommended (C:N) ratio, abattoir waste and primary sludge have a too low (C:N) ratio, meaning they are too rich with nitrogen and are therefore inclined to ammonia inhibition, while straw and paper waste have a too high (C:N) ratio meaning there are too rich with carbon and are therefore inclined to have low biogas yield.

2.3.4.2. Total solids (TS)

Total solids (TS) is the amount of solids in a substrate or feedstock, it's the matter that is left after all water is evaporated (Rohlich et al., 1977). TS is a critical parameter of AD since biogas is produced from solids only. TS also affects the digester size hence its cost, for a given biogas yield, the lower the TS, the bigger the digester to accommodate the larger water quantity and vice versa. Monnet (2003) classified AD systems according to their TS as follows: high, medium and low solids with above 40%, between 40% and 10% and below 10% total solids respectively (Monnet, 2003). Agama Biogas (2009) suggest a different TS classification of dry and wet AD systems with above 25% and below 10% total solids respectively (Agama Biogas, 2009).

2.3.4.3. Volatile Solids (VS)

Volatile solids are the amount of biodegradable solids in the total solids. As with TS, for a given biogas yield, the higher the VS the lower the digester size and its costs. Equation 5 below describes the calculation of VS (Deublein & Steinhauser, 2011).

$$VS(\%) = \frac{VS_{in}(ton)}{TS_{in}(ton)} * 100\%$$

Equation 5: (VS) as a fraction of (TS)

2.3.4.4. Volatile solids (VS) destruction rate

The destruction rate is one of the most common criteria for AD systems (Mata-Alvarez et al., 2000). The destruction rate is also known as degree of decomposition is the percentage of VS destroyed\biodegraded by the anaerobic bacteria. Equation 6 below describes the calculation of destruction rate marked with "X" (Zamudio Canas, 2010).

$$X(\%) = \left(\frac{VS_{in} - VS_{decomposed}}{VS_{in}}\right) * 100\%$$

Equation 6: Destruction rate as a function of VS

Where for a given amount of feedstock, "VS_{in}" is the amount of VS in the feedstock as it enters the anaerobic digester and "$VS_{decomposed}$" is the amount of biogas produced, on a mass base (Zamudio Canas, 2010). Mass balance is the fundamental principle behind the destruction rate equation (Felder & Rousseau, 2008). Similarly, the same method can be used to calculate the amount of digestate (Karellas et al., 2010). The destruction rate is a function of the feedstock, The AD system setup and the other AD parameters. The destruction range is typically 27%-76% with an average of 43.5%. The biogas yield has a direct positive correlation to the destruction rate (Deublein and Steinhauser, 2011).

2.3.4.5. Biogas yield and composition

Biogas yield is the amount of biogas generated in an AD process. Biogas yield is typically measured in cubic meters of biogas per ton of VS_{in}, where biogas production is the total amount of biogas produced over a certain time period, measured in m^3 (Sosnowski et al., 2003). Biogas yield, quantity and quality are essential parameters of AD systems, as bio-methane is the most commonly desired output of AD.

One approach, the chemical approach, to calculate biogas production is using Buswell's stoichiometric equation:

$C_nH_aN_dO_b$ + [A] H_2O -----> [B] CH_4 + [C] CO_2 + dNH_3 Equation 7

Where A, B and C are coefficients of the chemical reaction, which are a function of the feedstock material (Sosnowski et al., 2003).

Van Lier et al. (2008) points out that Buswell's stoichiometric equation is limited since it assumes that all the feedstock is converted to biogas and neglects the effluent production (Van Lier et al., 2008). This is limiting since effluent production is an integral part of the AD process (Agama Biogas, 2009).

Another approach to estimate biogas production is based on a mass balance approach. Biogas yields for different substrates are empirically measured as m^3 biogas per ton of VS fed and the biogas amount is calculated as the multiplication of TS, VS and biogas yield (Karellas et al., 2010).

Sosnowski et al. (2003) also suggest a formula to calculate the biogas quality\composition:

$$\%CH_4 = \left(4 + \frac{a}{n} - \frac{2b}{n} - \frac{3d}{n}\right)$$

Equation 8

Where a, b, d and n are coefficients of the chemical reaction, which are function of the feedstock material (Sosnowski et al., 2003).

2.3.4.6. Temperature

The AD process bacteria are dependent on temperature, in general the higher the temperature the higher the biogas production and waste stabilization (up to 70°C). Literature points to three main AD temperature regimes: psychrophilic or ambient ranges between 15-20°C, mesophilic ranges between 20-45°C and thermophilic ranges between 50-65°C. The optimal mesophilic and thermophilic temperature ranges are reported to be 30-38°C and 44-57°C respectively (Igoni et al., 2008; Nohra et al., 2003). According to Deublein & Steinhauser (2011) the mesophilic range is 32-42°C and the thermophilic range is between 48-55°C (Deublein & Steinhauser, 2011).

The most common AD temperature regime is mesophilic, about 62% of AD plants in Europe operate under mesophilic conditions (Igoni et al., 2008; Karagiannidis and Perkoulidis, 2009). Most of the methanogenic archaea belong to the mesophilic range (Vindis et al., 2009). Though thermophilic conditions are associated with the highest biogas production and waste stabilization, which can be expressed in the highest reduction of chemical oxygen demand (COD), thermophilic bacteria are more sensitive to variations in temperature and other conditions (i.e. PH level). In addition thermophilic temperatures requires higher energy inputs and if not compensated with continuous higher biogas yield, the overall thermophilic process energy efficiency may be lower than of mesophilic (Coelho et al., 2011; Gannoun et al., 2009; Dugba and Zhan, 1999). This is also supported by Tchobanoglous et al. (1993) who argue that running an AD process at a temperature range of 25-35°C leads to the best combination of bacteria growth, biochemical reaction rate, biogas and methane yield while maintaining process stability (Tchobanoglous et al., 1993). Vindis et al. (2009) also claimed that though thermophilic conditions may lead to eight times more biogas production and higher destruction of VS, it's not commonly practiced due to higher energy inputs and process sensitivity (Vindis et al., 2009). Deublein and Steinhauser (2011) found that under thermophilic conditions, a 2°C variation may lead to about 30% biogas yield loss.

Though not as common in industrial scale AD systems, psychrophilic conditions are often practiced in small scale systems and rural areas (Nohra et al., 2003). In their work on AD of MSW, Tchobanoglous et al. (1993) argues that operating temperature below the mesophilic range leads to foaming and slow down of the AD process due to low degradation rate of long chain fatty acids. On the contrary, in their work on AD of breweries waste, Connaughton et al. (2006) claims that similar biogas yields and organic loading rates were observed at psychrophilic and mesophilic conditions (Tchobanoglous et al. 1993; Connaughton et al. 2006).

2.3.4.7. pH

The products of the different intermediate stages of AD influence the overall reactor PH level, in an ideally balanced system the PH level is self-stabilised. Volatile fatty acids (VAF) generated in the acidogenic stage, are amongst the stronger contributors to reduction in the PH level, or an increase in the acidity, accumulation of volatile fatty acids and the resulting lower PH levels harms the growth and functionality of the methanogenic archaea and therefore reduces the biogas yield and quality. In a balanced system, the volatile fatty acids generated by the acidogens, are consumed in the same rate by the methanogens (Viessman and Hammer, 1993; Eckenfelder, 2000).

As illustrated in figure 10, the ideal PH level for AD systems is 6.5-7.5, maintaining a balanced PH levels can lead to up to 35% increase in the cumulative bio methane production (Ward et al., 2008).

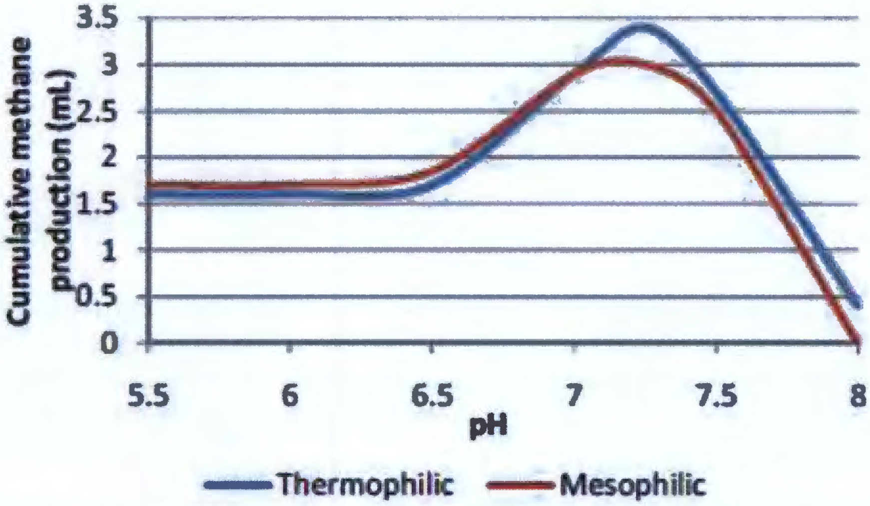


Figure 10: Optimal range of pH for anaerobic digestion of organic waste and its effect on cumulative methane production
(Adapted from Ward et al., 2008)

Another important effect of PH level on AD systems is the conversion of soluble carbon dioxide (CO_2) into hydrogen carbonate ions (HCO_3-), which takes place in the acidogenic stage, this conversion rate is a function of the PH level, and it increases the buffering capacity of the system i.e. it assists in maintaining a stabilized acidic levels (Igoni et al., 2008). Zaher et al. (2007) defines alkalinity buffering capacity as "the ability to resist pH change upon formation of acid during digestion" (Zaher et al., 2007).

AD systems that mainly operate with fast biodegradable feedstocks such as food waste, are harder to balance in terms of PH levels since the hydrolysis and acidogenic reactions accrues faster than the methanogenic reaction, leading to accumulation of volatile fatty acids, inhibition of the methanogenic archaea and decrease in the quality and quantity of the biogas (Igoni et al., 2008).

A common practice to balance PH levels and create PH buffer in AD systems, is the use of alkaline, such as $CaCO_3$, Na(OH), $Ca(OH)_2$ and $NaHCO_3$. A research by Brummeler and Koster (1989) demonstrated that sodium bicarbonate ($NaHCO_3$) is the best alkaline buffer, under dry conditions, at a solids to buffer ratio of 0.06 (Brummeler and Koster, 1989).

2.3.4.8. Waste particle size

To a large extent, the rate of biodegradation and respective biogas yield is a function of the waste\feedstock particle size, the smaller the particles the larger the surface\contact area and the respective biogas production. Smaller particle size also has the advantage of smaller equipment requirements such as pumps and mixers and respective smaller capital and operational costs. Shredders and grinders are typically used to reduce the particle size (Izumi et al., 2010; Mshandeteet al., 2004; Igoni et al., 2008; Agunwamba, 2001).

2.3.4.9. Organic loading rate and hydraulic retention time

Organic loading rate (OLR) is an important control parameter for AD systems, it has a strong correlation with the system biogas and effluent quantity and quality. OLR indicates the biological conversion capacity of an AD system, it is calculated according to equation 9 (Chaudhary, 2008).

$$\textbf{Organic Loading Rate} = \frac{\textbf{Organic Load/day}}{\textbf{Volume}} \qquad \text{Equation 9}$$

Where Volume is the volume of the anaerobic digester (Chaudhary, 2008).

The higher an AD OLR capacity the higher the AD system's biological efficiency i.e. its ability to handle more feedstock and produce more biogas at the less time. OLR is measured in units of g VS/cm3/day or kg VS/m3/day, where VS is volatile solids, which is the percentage of organic solids in the total solids (TS), and volume refers to the digester\reactor volume (Rincon et al., 2007). Another expression of OLR is food to inoculum ratio (F:I) (Igoni et al., 2008).

Due to the faster nature of the hydrolysis and acidogenic stages, exceeding an AD system's sustainable OLR results in accumulation of volatile fatty acids, decrease of the PH level, inhabitation of the methanogenic archaea and decrease of the biogas yield and quality. In such cases the amount of feedstock or the OLR must be reduced (Igoni et al., 2008).

Hydraulic and solid retention time (HRT and SRT respectively), is another important control parameter for successful operation of an AD system and directly related to OLR. HRT and SRT is the time specific water and solid particles spend in the AD reactor respectively. HRT and SRT are calculated as follows:

$$\boldsymbol{HRT = \frac{V}{Q}} \qquad \text{Equation 10}$$

Where HRT is measured in days, V is the digester volume in cubic meters and Q is the volumetric flow rate in cubic meters per day (SRT is calculated the same only that the Q refers to the solids volumetric flow rate rather than the liquid). HRT and SRT have a direct correlation to OLR i.e. the longer the HRT\SRT is the higher the system OLR, at given conditions, since it allows the different bacteria more time to process the feedstock and more time to reach balanced growth (Chaudhary, 2008; Dennis and Burke, 2001).

A sustainable HRT and SRT limit is a function of the temperature, feedstock composition, type of AD technology and the biological balance of the reactor at a given time. For example, the HRT of mesophilic

AD systems varies between 10-40 days (Chaudhary, 2008). According to Zamudio Canas (2010), the optimum HRT for large scale AD systems is 14-30 days. Zamudio Canas (2010) also explains that for some AD technologies such as complete stirred tank reactor (CSTR) and plug flow digesters, the HRT and SRT are coupled, where in batch reactors HRT is typically shorter than SRT. Shorter HRT and SRT means more biogas production per digester volume, since the biogas yield is an exponential process, where most of the biogas is produced in the early stages, however longer HRT and SRT allow for higher VS destruction, therefore the HRT and SRT should be designed according to the AD systems targets and priorities (Zamudio Canas, 2010).

2.3.4.10. Mixing

Mixing in the AD reactor is directly correlated with increased biodegradation rate, biogas yield and waste stabilization. Mixing allows maintaining uniform conditions inside the reactor, such as temperature, PH level, and substrates concentration. Over and above, mixing helps to release biogas trapped in gas pockets inside the substrate, this is especially essential in batch reactors (Karim et al., 2005). There are three main types of mixers: mechanical, jet\liquid and gas. Mechanical mixers are more suitable and common to find with high solid concentration substrates and gas mixing systems are more applicable for low solid concentrations, liquid\jet mixers suite the range in between. In small scale and rural application it is common to find no mixing at all (Stafford, 1982; Igoni et al., 2008).

2.3.4.11. Co-digestion

The term co-digestion refers to AD of different feedstock especially carbon and nitrogen rich feedstock, co-digestion of carbon and nitrogen rich feedstock allows adjusting the (C:N) ratio to optimal levels and achieving the full potential of biogas yield (Zamudio Canas, 2010). This is also expressed in shorter HRT for a given amount of biogas. Well balanced co-digestion will typically have an HRT of 21 days where for the same amount of biogas it will take an HRT of 30 days with one feedstock stream (Luste & Luostarinen, 2010).

The benefits of co-digestion are: higher biogas yield, shorter retention time, higher VS destruction, higher OLR and financial benefits resulting from increased performance and sharing of equipment. This is achieved due to a correct (C:N) ratio, dilution of inhibiting compounds such as ammonia and synergetic effects between different bacteria that can be found in different waste streams (Sosnowski et al., 2003; Zamudio Canas, 2010). One of the challenges of co-digestion is the logistics and costs involved with transporting different feedstock streams in to one central point (Rohlich et al., 1977).

2.3.5. Main types of AD feedstocks

There are many potential types of feedstocks that can be processed in an AD system, these can be broken down into four main categories: sewage, agriculture waste (animal waste and crop residue) and energy crops, industrial waste and municipal waste. Figure 11 below shows the main feedstock categories and examples from each, sewage waste is excluded (Klass, 1998).

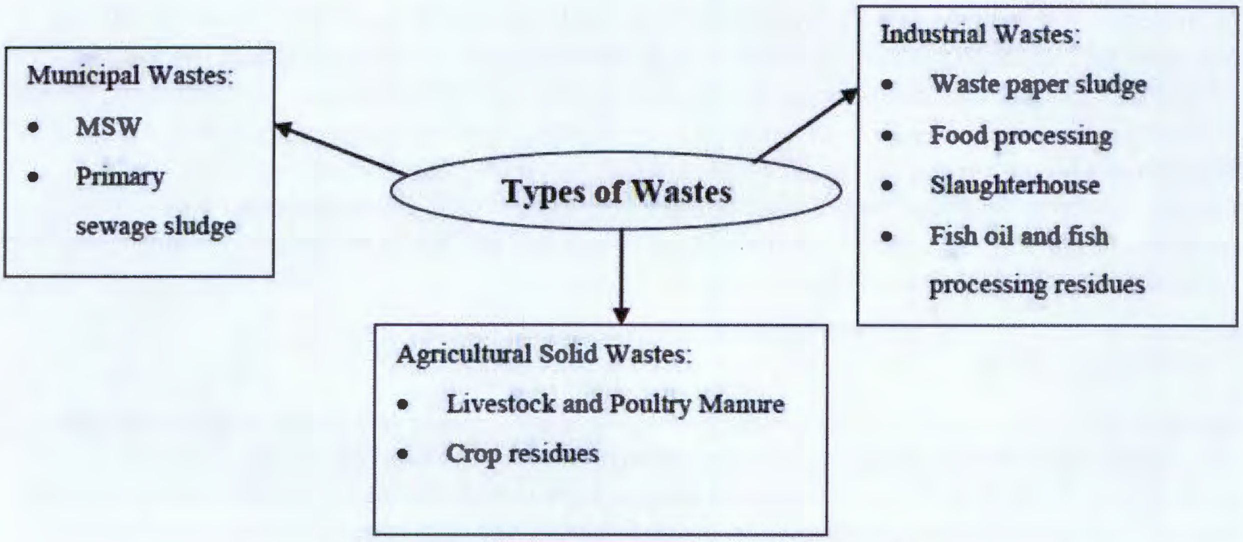


Figure 11: AD feedstock classification and examples
(adopted from Klass, 1998).

Section 2.3.5.1. – 2.3.5.3 explain the three main types of feedstocks relevant for this study, out of which food waste and source separated organics (SSO) are most relevant since these are the designated feedstocks of the project assessed here. Garden waste and high protein feedstock are also explained since they are available in the project area and traces of them might be found in the project feedstock.

2.3.5.1. MSW, food waste and SSO

MSW is the waste generated at households, it contains paper, glass, metals, garden trimming and food waste (USEPA, 2010). Food waste is also regarded as kitchen waste or market waste, it is typically generated at households, food retailers and food industries. Food waste is typically the biodegradable fraction of MSW and it accounts for 30-50% of MSW (Deublein & Steinhauser, 2011). Source separated organics (SSO) is the organic portion of MSW, separated at its source of origin – this is typically also food waste. Food waste is regarded as one of the best types of AD feedstock since it is high in organic content, high in protein and lipids and easily biodegradable. One typical challenge with food waste is a relatively fast hydrolysis step which may lead to accumulation of VFAs, decrease of PH level and as a result inhibition of the methanogens archaea (Tajarudin, 2006).

Another common challenge with food waste relates to food waste rich in protein and as a result have low (C:N) ratio. With such feedstock, an excess of organic nitrogen degradation may occur, leading to ammonia (NH_3) accumulation and resulting in inhibition of the methanogens archaea (Fricke et al., 2007).

Typical food waste biogas methane content is reported to be 70-80% and have a biogas yield of 500-600 mL/g VS, this results in a bio-methane yield of about 400 mL(CH_4)/g VS (Banks et al., 2011).

2.3.5.2. Garden waste and crop residue

Garden waste includes waste from municipal and residential plant material. To some extent energy crops can also be considered under this category, though these are typically more suitable for AD as a dedicated feedstock (Kalra and Panwar, 1986). Garden waste has several critical inhibiting challenges concerning the bacteria involved in the AD process and the process kinetics (Speece, 1987). Literature reports on several challenges concerning garden waste: too high lignin and cellulose content inhibiting biodegradation, too high carbon content and (C:N) ratio, presence of traces of pesticides and herbicides that can damage the AD bacteria and process, may release hydromethyl fufural, levulinic acids and formic acid which are harmful for the AD process, and some plants may contain resin for natural protection from biodegradation which will also harm the artificial AD process (Khalil et al., 1991; Chakraborty et al., 2002; Speece, 1987).

In light of these challenges and in order to improve the AD process kinetics, pre-treatment is often exercised with garden waste. Pre-treatment such as acid and base hydrolysis are common practices (Speece, 1987).

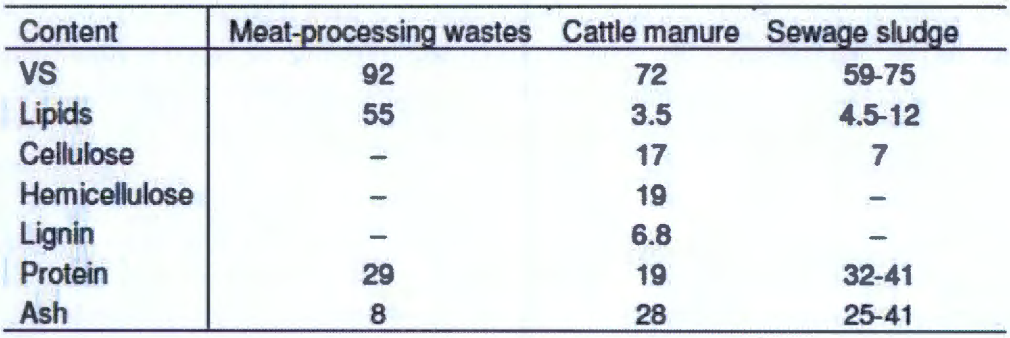
2.3.5.3. Animal waste

AD of animal waste has been widely practiced since the 1970s, first applications were mainly aimed to treat the waste rather than for renewable energy applications (Monnet, 2003). Animal waste is often regarded as protein rich feedstock. Chicken, cows and pig waste are the most common animal waste treated with AD. Slaughterhouse waste, sewage sludge and silage maize are also considered protein rich feedstock.

The most common challenge with animal waste and protein rich waste is high nitrogen content and low (C:N) ratio leading to ammonia inhibition (Zeeman et al., 1985; Krylova et al., 1997; Hansen et al., 1998; Chen et al., 2008). As animal waste and protein rich waste may vary significantly from case to case, so is the level of ammonia inhibition reported in literature. Hansen et al. (1998) for example used ammonium chloride (NH_4Cl) to change the ammonia concentration, in a 118 mL batch reactor, loaded with 6 mL of cow manure, which equated to about 3 g VS/L, his results showed that inhabitation occurred at a PH level of 8 and an ammonia concentration of 1.1 g N/L (Hansen et al., 1998).

Due to its nature, animal waste and protein rich waste will typically have lower OLR, higher OLR will result in lower biogas yield and quality and inhibition of the AD process (Luste, 2010). For example meat processing waste should have an OLR of 1-3 kg VS/m^3/day (Rosenwinkel and Meyer, 1999) and mechanically treated abattoir waste should have an OLR of 4-4.2 kg VS/m^3/day (Murto et al., 2004).

Table 5 below shows relevant characteristics to AD process of protein rich waste:



Content	Meat-processing wastes	Cattle manure	Sewage sludge
VS	92	72	59-75
Lipids	55	3.5	4.5-12
Cellulose	–	17	7
Hemicellulose	–	19	–
Lignin	–	6.8	–
Protein	29	19	32-41
Ash	8	28	25-41

Table 5: protein rich waste characteristics
(adopted from Pavlostathis and Giraldo-Gomez, 1991; Luste, 2011)

Another common problem with animal waste, sewage sludge and abattoir waste is high pathogens content, pathogens are bacteria and viruses that may cause diseases. If pathogens are fed to an AD system and are not treated adequately, for example with pasteurization, they may be found in the process effluent and lead to contamination of water sources and drinking water (Chen et al., 2008).

Other challenges with animal waste are capturing and transporting it. Capturing animal waste is often difficult since many farm animals graze in pastures, housed animals waste is difficult to capture due to high animal density and the need to avoid stressing the animals in order not to harm their production. Transportation of animal waste is often not cost effective since the animal waste is typically low in density and high in moisture content, therefore most animal waste AD applications are located in the waste producing farm itself (Monnet, 2003).

2.3.6. AD kinetics and process indicators

AD is a natural process that people have been using to their advantage for a very long time, however when implemented on a commercial scale, optimum operation is desired in order to recover costs and realize profits. For optimized AD operation, understanding of the AD process, monitoring key indicators and controlling key parameters is essential. Optimized AD process typically means high and stable biogas production with high methane content and high biodegradation rate. A good process indicator is one that can be directly measured and reflect the status of the desired AD results (Boe et al., 2010). There is no consensus on the best process indicators, the relevance of process indicators is to a large degree a function of the process setup and its specific state (Chen et al. 2008).

Chen at al. (2008) point out that the most effective AD process indicators are NH3, light and heavy metals, organic acids and sulphides concentrations (Chen at al. 2008). Boe et al (2010) studied and assessed the effectiveness and response time of common AD process indicators and ranked them in the following order:

1. Amount of dissolved H2
2. PH level
3. Acetic acid concentration
4. Butyric acid concentration (as an indication to glucose digestion rate)
5. Propionic acid concentration (as an indicator to system overload)
6. Biogas yield and composition (Boe et al. 2010).

Biogas yield is the most common practiced AD process indicator, mainly since it is relatively easy to measure and indicates the final desired result. The main disadvantages of relying on biogas yield as the main process indicator is the response time, i.e. by the time biogas yield or composition might drop, the process may already be inhibited in a way that will be very hard to stabilize (Moletta et al., 1994, Boe et al., 2010).

The aim of process indicators therefore is to detect inhibition of the AD process. Inhibition of the AD process is a result of an unbalanced microbial activity, typically the methanogenic and the acetogenic bacteria groups are more sensitive than the acidogenic and hydrolysis bacteria to process parameters like PH and temperature, therefore inhibition is typically a result of shift towards the later microbial groups (Wang et al., 1999; Deublein and Steinhauser, 2011). Organic acids accumulation together with PH level is the best indicator for such shift in the microbial activity (Kroeker et al., 1979).

Section 2.3.6.1 to 2.3.6.5. below, discuss and explain the most common process indicators reported in literature and their respective process parameters, which enables control of process inhibition. The process indicators discussed below are: volatile fatty acids, light metal ions, organic compounds, sulphur and ammonia.

2.3.6.1. Volatile fatty acids (VFAs)

VFAs are formed in the hydrolysis and acidogenic stages and consumed in the acetogenic and methanogenic stages, as such they are the main intermediate products of the AD process. Therefore accumulation of VFAs is considered by many to be a critical AD process indicator (Jacobi et al., 2009; Molina et al., 2009, Ahring et al., 1995, Hill et al., 1987). Coupled with a drop in PH level, accumulation of VFAs is considered as certain indicator for process inhibition and eventually failure (Babel et al. 2004)

The main VFAs of AD process are: iso-caproate, caproate, iso-valeric, valeric, iso-butyric, burtyric and propionic. These VFAs are first converted to acetic acid, which is then consumed by the methanogenic bacteria to produce methane. The conversion rate of VFA's to acetic acid is a function of methanogenic bacteria activity and the respective conversion of acetic acid to biogas (Wang et al. 1999)

Wang et al. (2009) described the sequence of an inhibition process as follow:

- Accumulation of VFAs
  - Drop in PH level
    - Inhibition of acidogenic and methanogenic bacteria
      - Reduction in biogas and methane production
        - More accumulation of VFA's (Wang et al. 2009)

Analysts agree that apart from accumulation out of the VFAs, accumulation of propionic acid is a main cause and indicator to process inhibition and eventually failure. This is mainly due to the fact that propionic acid has a slow degradation rate and strong inhibition effect on methanogenic archaea. Propionic acid is a result of oxidation of odd-number carbon atoms (Wang et al., 2009; Barredo and Evison, 1991; Yeole et al., 1996). Propionic acid concentration has a reverse correlation to PH level and often occurs at an exponential rate, therefore inhibition caused by increase in propionic acid is often irreversible (Wang et al., 2009). For example, Yeole et al (1996) showed that at a propionic acid concentration of 5,000 mg/L and a PH level of seven, a 22-38% decrease in methane yield was experienced (Yeole et al., 1996).

Other than changing the AD process parameters, mainly the feedstock quality and quantity, there are some ways reported in literature to combat VFA's inhibition. For example adding butyric acid may slow down the inhibition rate and lead to improved bio-methane yield (Demirel et al., 2002; Wang et al., 2009).

2.3.6.2. Light metal ions

Light metal ions are essential for the AD process as micronutrients stimulating bacteria activity and growth, however at concentrations above moderate, they can cause a significant process inhibition and even failure. Light metal ions increase the slat level and as a result, the osmotic diffusion of liquids from bacteria cells, leading eventually to their dehydration. The most relevant light metal ions to AD are Sodium, magnesium, potassium and calcium. The source of light metal ions in AD is typically from the degradation of organic content and added chemicals for PH control (Chen et al., 2008).

There is no consensus on light metal ions concentration that lead to inhibition. For example in mesophilic conditions, Sprott and Patel (1986) and Kugelman et al. (1971) reported that the optimal sodium (NA+) concentration should be 350 mg/L and 230 mg/L respectively (Sprott and Patel, 1986; Kugelman et al., 1971). However there is a general consensus about the inhibition leading concentration of sodium to be 3,500-5,500 mg/L and above 8,000 mg/L, leading to medium and aggressive inhibition respectively (Chen et al., 2008; Cheng, 2010).

2.3.6.3. Organic compounds

The most common organic matter leading to AD process inhibition are long chain fatty acids (LCFAs) such as: oleic acid, Cypric acid, lauric acid, capric acid, mystiric acid, carboxylic acids, ether, benzenes, halogenated hydrocarbons, alkanes and phenols. Organic matter with tendency to absorb in sludge or low solubility, are more prone to accumulate to inhibition leading concentration levels (Chen et al., 2008).

The toxicity of organic compounds is generally a function of their concentration, loading rate, temperature and retention time (Yang and Speece, 1986). Organic compounds and LCFA's, absorbs into the AD bacteria membrane, mainly the methanogen archaea, interfering with the bacteria ability to transport other substances. Mesophilic bacteria are more immune to the effects of LCFAs than thermophilic bacteria, this is mainly due to the differences in their cell wall to absorb and handle LCFA's. LCFA's negative effect can be mitigated by adding insoluble salts to the AD process , calcium (CA+) addition is a common practice for that aim (Chen et al., 2008).

2.3.6.4. Sulfur

Sulphate reducing bacteria (SRB) are associated with the acidogenic bacteria. During the fermentation of amino acids, they process sulphate into sulphide by using electrons from hydrogen (H_2) and organic molecules (Salminen and Rintala, 2002). For that reason, SRBs compete directly with the acetogenic bacteria and methanogenic archaea on substrate such as hydrogen and organic acids (Chen et al., 2008). In the competition over substrate, SRB has a kinetic advantage over acetogenic bacteria and methanogenic archaea (Chen et al., 2008), where hydrolysis and acidogenic bacteria are less affected by sulphide. Over and above, sulphide produced by SRB is toxic to methanogenic archaea and may lead to inhibition and reduces quality and quantity of biogas (Wang et al., 2008).

Sulphur (H_2S) is considered toxic to some bacteria, such as the methanogenic archaea, since it can absorb in the bacteria cells and as a result: fuse with native proteins to form sulphide and disulphide, interfere with enzymes activity and reduce the bacteria ability to assimilate sulphur (Cheng, 2010). Furthermore, at a concentration of about 23 mg/L, sulphide may increase ammonia inhibition (Hansen et al., 1999). The negative effect of sulphide can be balanced by adding activated carbon as it absorbs the sulphide into its surface (Salminen and Rintala, 2002).

2.3.6.5. Ammonia

Under anaerobic conditions, ammonia (NH_3) is the product of nitrogen compounds degradation (Chen et al., 2008). In AD ammonia is found in two main forms – free ammonia (FA) and ammonium (NH_4+) – which are also the main forms of inorganic nitrogen. There are two main ways in which ammonia may lead to inhibition of AD process: conversion of ammonia to ammonium by bacteria cell diffusion and direct diffusion of FA to bacteria cells. In the first case the defused ammonium causes interference with enzyme activities, and in the latter case the defused FA leads to potassium deficiency, both eventually leads to overall process inhibition (Sprott and Patel, 1986; Gallert et al., 1998; Hansen et al., 1998). Out of the two, FA is recognized as the main cause of inhibition as it penetrate cells membranes more easily than ammonium (Kroeker et al., 1979; de Baere et al., 1984; Tchobanoglous et al., 1993).

Koster and Lettinga (1988) showed that methanogenic archaea are much more sensitive to ammonia that the other AD bacteria groups. In their study they found that an increase in ammonia concentration increase of about 41% or from 4,051 to 5,734 mg/L resulted in 56% reduction in methanogenic bacteria activity, while acidogenic bacteria activity did not change. This is further supported by Kayhanian (1994) who claims that methanogenic bacteria are much more sensitive to the effects of ammonia than any other AD bacteria group.

There are many ammonia concentration threshold values leading to AD process inhibition reported in literature, the reason is that there are many factors affecting the threshold concentration such as: the type of feedstock, PH level, temperature, retention time, etc. (Chen *et al.*, 2008). Farina et al (1998) reported that inhibition of AD of poultry and pig manure occurred at ammonia concentration of 1.1 – 4 g/L (Farina et al, 1998). Work by Kroeker et al (1979) showed that general AD inhibition occurred at ammonia concentration of 1.7 – 14 g/L. A study by Buendia et al (2009) observed the effect of ammonium and found that at a concentration of 1.13 g/L a 50% reduction in bio-methane production occurred. Overall, many studies agree that ammonium inhibition occurs at a range of 1.5- 2.5 g/L, with non-adopted cultures (Koster and Lettinga, 1984; Hashimoto, 1986; Van Velsen, 1979 cited in Luste, 2011). Ammonia threshold concentration leading to process inhibition may be increased, if ammonia concentration is gradually increased, allowing the bacteria Culture sufficient time to adopt (Luste, 2011).

Though in general, higher biogas yields are achieved at low ammonia concentrations, or with low protein feedstock, many agree that allowing sufficient adaptation period for the AD bacteria to ammonia concentration may increase the ammonia inhibition threshold significantly (Koster and Lettinga, 1984; Borja et al., 1996; Melbinger and Donnellon, 1971). Sufficient adaptation period allows a stable shift in the methanogenic archaea population toward methanogenic species that are more immune to high ammonia concentration (Melbinger and Donnellon, 1971; Angelidaki et al., 1993).

PH level is another important factor of ammonia inhibition, PH level in AD systems affect the concentration of FA and bacteria growth, this is critical since FA is toxic, mainly to methanogenic archaea. High PH levels leads to speciation of ammonium into FA, as described by equation 11 (Chen et al., 2008).

$$NH_4^+ \leftrightarrow NH_3\,(aq) + H^+$$

Equation 11

As a result of the AD process, ammonia is processed into ammonium leading to increase in PH levels, this must be kept under control, not to allow PH levels to increase beyond an inhibition threshold. Low PH allows an ammonia buffer for the AD system (Salminen and Rintala, 2002; Speece, 1983). Maintaining sufficient levels of carbon in the AD system will accommodate such a PH and ammonia buffer. For example Boardman and McVeigh (1997) showed that a decrease in PH level from 7.5 to 7, resulted in four time increase of biogas yield, with cattle manure (Boardman and McVeigh, 1997).

Temperature is another important factor for ammonia inhibition, as temperature effects the AD bacteria growth and activity and as a result, the FA concentration. Therefore thermophilic AD is more sensitive to ammonia inhibition than mesophilic AD, especially with nitrogen rich feedstock (Braun et al., 1981; Parkin et al., 1983).

There are several techniques reported in literature to combat ammonia inhibition:

- Direct removal of ammonia, below inhibition threshold concentration level. This is typically done by air stripping or chemical precipitation of ammonia (Chen et al., 2008).
- Adjusting the (C:N) ratio by controlling the type of feedstock and its loading rate, to reduce the amount of excess ammonia (Chen et al., 2008).
- Two stages AD system, separating the methanogenic phase from the rest, allowing better control of the methanogenic archaea exposure to ammonia. This is effective since the methanogenic archaea are much more sensitive to ammonia concentration (Wang and Banks, 2003; Cuetos et al., 2008).

All methods have proven to be effective to prevent ammonia inhibition, especially with nitrogen rich substrate (Chen et al., 2008).

2.3.7. Uses of biogas

Biogas has a high methane content, and can be a substitute for natural gas, and therefore used in energy applications where natural gas is used. Unlike natural gas which is mined, biogas is generated from renewable energy sources and has several environmental and in some cases financial advantages. Table 6 below shows a typical composition of biogas from two different studies (i.e. Igoni et al., 2008; Deublein & Steinhauser, 2011).

Constituent	Composition	
	Igoni et al., 2008	Deublein & Steinhauser, 2011
Methane (CH4)	55-75%	55-75%
Carbon dioxide (CO2)	30-45%	25-50%
Hydrogen Sulphide (H2S)	1-2%	0-0.5%
Nitrogen (N2)	0-1%	0-2%
Hydrogen (H2)	0-1%	0-0.05%
Carbon monoxide (CO)	Traces	
Oxygen (O2)	Traces	
Water (H2O)		1-5%

Table 6: Typical biogas composition
(adapted from Igoni et al., 2008; Deublein & Steinhauser, 2011)

The main applications of biogas are in electricity generation and co-generation (heat and electricity), transportation fuel, domestic and industrial heating and lighting. One of the advantages of biogas is the ability to store it fairly easily, even in the AD reactor itself. Biogas is often used at the point of generation since its energy density is relatively low (in comparison with diesel for example), except for gas grid applications where the biogas is injected to a natural gas grid, in such applications the biogas is typically purified to bio methane (biogas with methane content above 90%). In order to transport biogas, it must be purified to bio methane and compressed or liquefied in order to increase its energy density and energy transportation efficiency (Greben et al., 2009; Igoni et al., 2008). Figure 12 below shows some of the different applications of biogas (Appels et al., 2008).

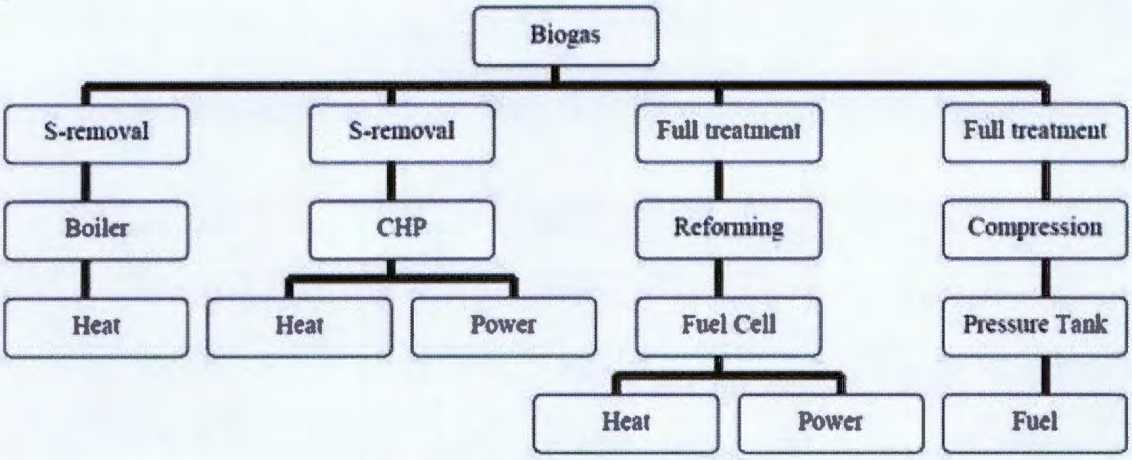


Figure 12: Biogas utilization pathways
(adopted from Appels et al., 2008)

The most common use of biogas to energy in large scale and commercial applications is for electricity generation. In this process the biogas produced is captured from the anaerobic reactor, cleaned (typically sulphur, carbon dioxide and hydrogen removal) and stored or pumped directly to a combined heat and power (CHP) unit. The CHP is an engine coupled with a generator with heat recovery system from the engine block and the engine stack. The biogas is used as a fuel to drive the engine which drives the generator to produce electricity. The heat captured can be used to heat the digester and for other renewable applications (Deublein & Steinhauser, 2011; IEA, 2008).

One of the environmental advantages of biogas CHP systems, connected to the utility grid or in island mode, is that they generate the electricity close to the point of origin and minimise transmission and distribution loses (IEA, 2008).

CHP units as well as most biogas renewable energy applications, use only the methane fraction of the biogas for energy generation, therefore other biogas components should be removed. The minimum recommended amount of methane for CHP units is 60% of the biogas on a volumetric base (Deublein & Steinhauser, 2011). Biogas upgrading technologies will be further discussed in section 2.3.8.

The electrical efficiency of CHP units is typically around 40%, while the overall energy efficiency, which is the electrical and thermal efficiency, is typically around 75-80%. Generally from one cubic meter of biogas, with 60% methane content, 6 kWh can be produced (Deublein and Steinhauser, 2011; IEA, 2008).

There are three main environmental benefits for AD and use of biogas (Kaparaju and Rintala, 2011):

1. GHG emissions avoidance resulting from AD of organic waste in a controlled system, capturing and using the produced biogas, instead of letting the organic waste to naturally decompose in an uncontrolled way.

2. GHG emissions avoidance resulting from fuel switch, i.e. using the biogas as an energy source instead of fossil fuels.
3. GHG emission avoidance and natural resources savings from conventional fertilizers production, when the AD effluent\sludge is used as organic fertilizer.

Methane has 21 times the GHG effect of carbon dioxide and therefore biogas applications tend to have strong GHG reduction effect (Clemens et al., 2006).

Zglobisz et al. (2010) stresses the GHG reduction benefits of utilizing AD technologies in waste management systems, for the organic fraction of municipal solid waste (OFMSW), since most OFMSW in the world is landfilled eventually releasing GHG to the atmosphere from natural AD processes (Zglobisz et al., 2010).

In the USA for example, biogas accounts for 1% of the electricity generated and reduces the power generation industry emissions by 10% (Igoni et al., 2008).

The landfill gas project in Ethekwini municipality in KZN, is a successful example of biogas application in South Africa. Landfill gas is harvested for electricity generation fed into the municipal grid. The project has been registered under the CDM mechanism for carbon credit from methane avoidance and fuel switch (Greben et al., 2009).

2.3.8. Biogas upgrading technologies

As previously discussed, methane is the only fraction of biogas that can be used for renewable energy generation, therefore other biogas components should be removed. The priority of the biogas, or its required methane content is a function of its application. Carbon dioxide is the second biggest component of biogas, there are five main types of carbon removal technologies: water scrubbing, high pressure swing adsorption (PSA), membrane separation, cryogenic and chemical absorption (Deublein & Steinhauser, 2011; IEABionergy, 2001; de Hullu et al., 2008).

Water scrubbing is the simplest carbon dioxide removal technology (de Hullu et al., 2008). Water scrubbing is based on the significantly higher solubility of carbon dioxide in water than that of methane. High pressured water is pumped through an absorption column, typically in a counter flow. The carbon dioxide is absorbed in the water while most of the methane remains and captured in a gas form. The same solubility difference principle is used to absorb sulphur (H_2S). One of the main disadvantages of water scrubbing is the high amount of water required, however this can be reduces by recycling the water (IEABionergy, 2001). Biogas qualities of 95-95% methane can be achieved, though the higher the biogas quality, the higher the energy and water consumption (Deublein & Steinhauser, 2011). Water scrubbing technologies are typically the biggest electricity consumers of biogas plants, they consume about 0.75 kWh of electricity per cubic meter upgraded biogas (Murphy et al., 2004; Murphy and Power, 2009).

High pressure swing adsorption (PSA) utilizes materials with high carbon dioxide absorption affinity. Pressure is introduced to increase the absorption rate of carbon dioxide while methane remains unabsorbed. After an absorption period and removal of the bio-methane, the pressure is released and the carbon dioxide is de-absorbed from the absorption material for the next batch. The main disadvantages of PSA is high operational costs and high capital costs compared to water scrubbing (de Hullu et al., 2008; Deublein & Steinhauser, 2011).

Carbon dioxide separation by membranes is done based on the different molecule size of carbon dioxide and methane. Biogas is pumped at a high pressure through a special membrane, which separates the methane and carbon dioxide. The main disadvantage of membrane technology is the high operational costs associated with its energy requirements and the frequent need to change membranes (de Hullu et al., 2008).

Cryogenic means temperatures below -150°C. Cryogenic biogas upgrading is based on the difference in liquefaction temperature between carbon dioxide and methane, high pressure is also introduced to decrease the liquefaction temperature. Cryogenic biogas upgrading is typically done at -170°C and 80 bar. The carbon dioxide then liquefies and is easy to separate from the methane. The main disadvantage of cryogenic biogas upgrading technology is the very high capital and operational costs. It is therefore most commonly used in very large applications and where the desired renewable energy form is liquefied biogas (LBG) (de Hullu et al., 2008).

Chemical absorption uses different materials that have a chemical reaction with the substrate that is desired to be removed. It is most commonly used to remove sulphur. The disadvantage of chemical absorption for carbon dioxide removal is its low separation efficiency (de Hullu et al., 2008).

2.4. Environmental legal requirements of a MSW AD to renewable energy project in RSA

The overall aim of an Environmental Impact Assessment (EIA) process is to promote responsible and sustainable development in the natural and built environments. Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. EIA's are aimed towards achievement of balanced and integrated social, environmental and economic performance – i.e. "People, Planet and Profit". The EIA and resulting mitigation of biophysical and social impacts are throughout a project's entire lifecycle (DEA, 2013).

There are two process leading to environmental approval of a project, basic assessment and full scoping assessment. The basic assessment and full scoping assessment processes should take about 6 and 12 months respectively.

An EIA involves (Van Zyle, 2015):

- Identification / assessment of baseline environment and impacts of a proposal upon the biophysical and social environment
- Specialist input, where necessary
- Public participation process

- The generation of feasible alternatives is required
- Mitigation measures are proposed to reduce or avoid impacts
- Opportunities to enhance positive impacts is made possible

Figures 13 and 14 below, describe the basic assessment and full scoping assessment processes respectively:

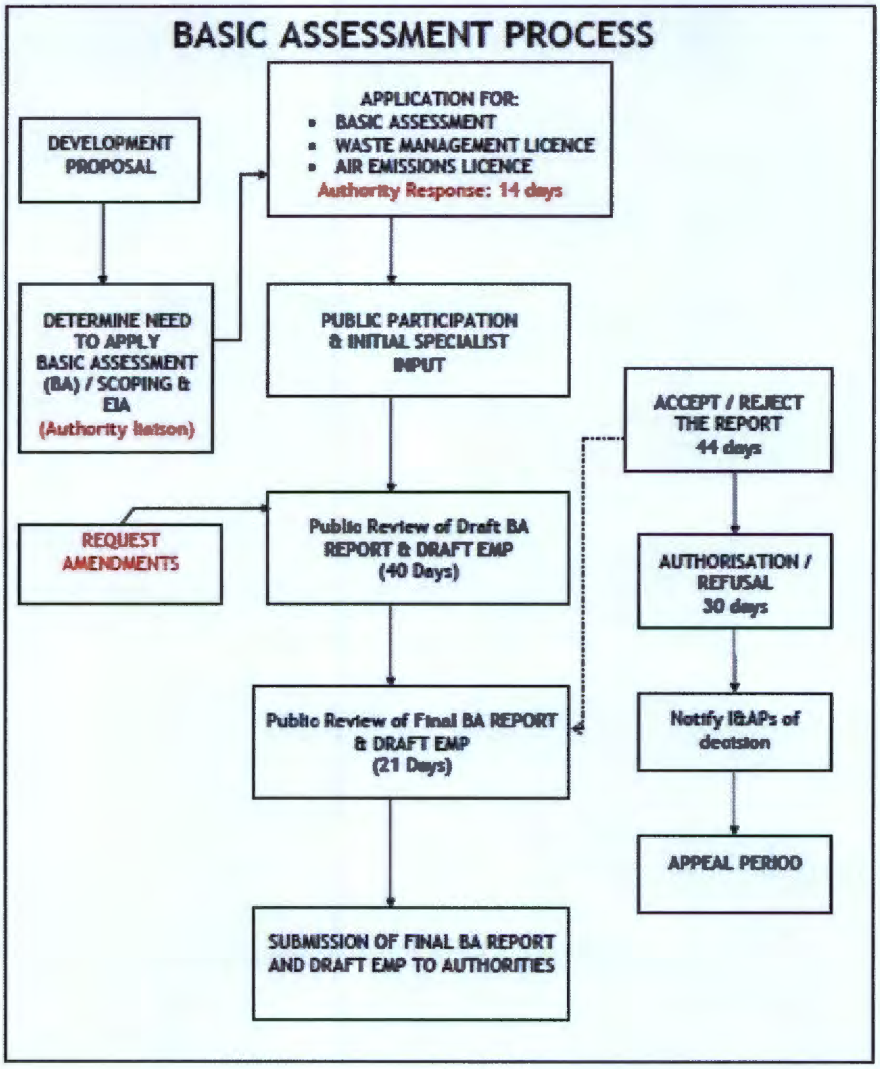


Figure 13: Basic assessment process
(adopted from DEA, 2013).

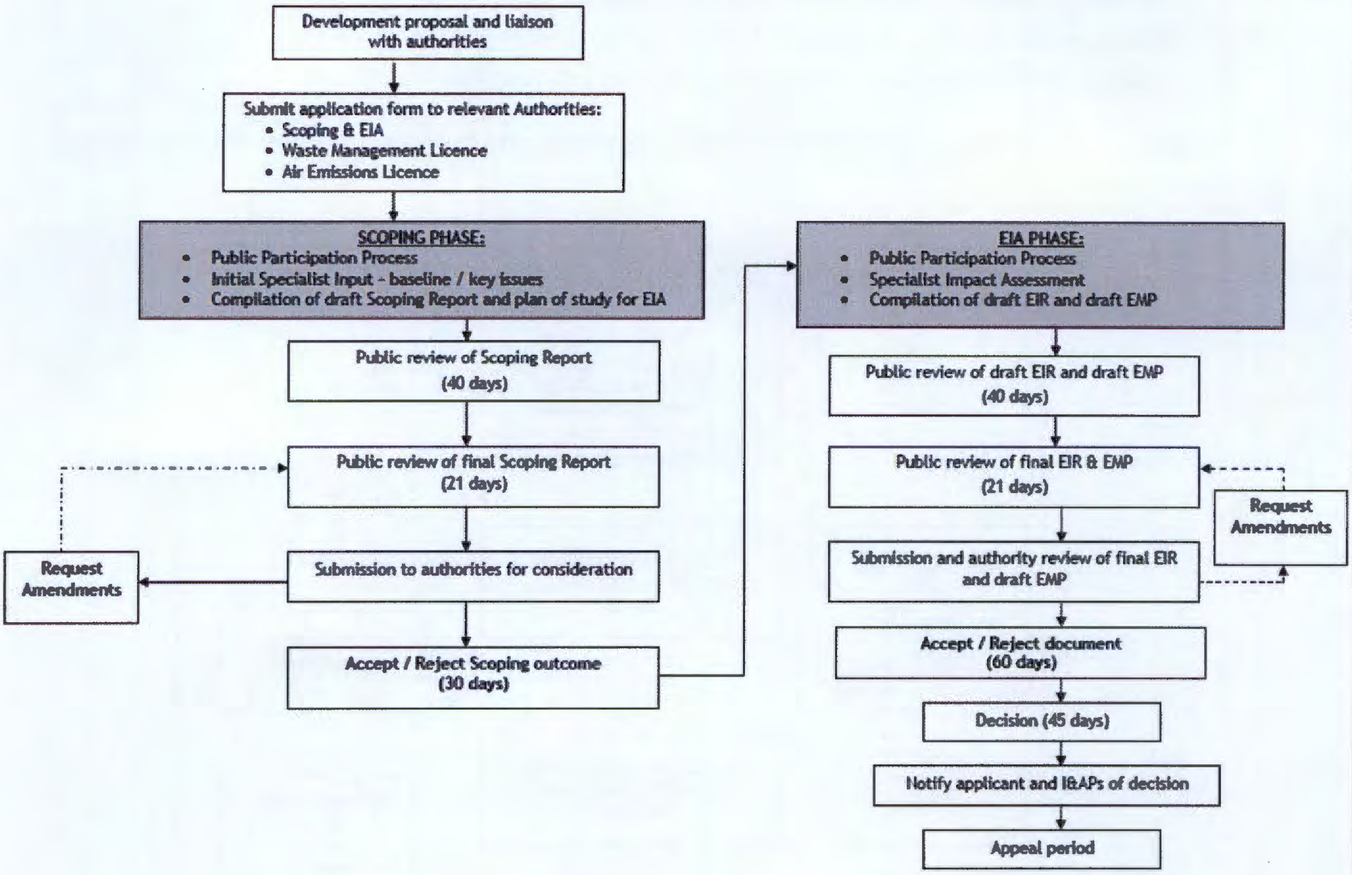


Figure 14: Full scoping assessment process (adopted from DEA, 2013).

The Department of Environmental affairs publishes a list of activities which triggers a basic assessment or a full scoping assessment. Below is a summary of the activities relevant for MSW AD to renewable energy projects, adopted from the National Environmental Management Act (NEMA) No. 107 of 1998 and The EIA Regulations GN No. R544, R545 and R546 of 2010 (DEA, 2013).

Listing Notice 2	Activity

Listing Notice 1	**Activity**
13	The construction of facilities or infrastructure for the storage, or for the storage and handling, of a dangerous good, where such storage occurs in containers with a combined capacity of 80 but not exceeding 500 cubic meters;
23	The transformation of undeveloped, vacant or derelict land to – (i) residential, retail, commercial, recreational, industrial or institutional use, inside an urban area, and where the total area to be transformed is 5 hectares or more, but less than 20 hectares, or (ii) residential, retail, commercial, recreational, industrial or institutional use, outside an urban area and where the total area to be transformed is bigger than 1 hectare but less than 20 hectares; - except where such transformation takes place – (i) for linear activities; or (ii) for purposes of agriculture or afforestation, in which case Activity 16 of Notice No. R. 545 applies.
24	The transformation of land bigger than 1000 square meters in size, to residential, retail, commercial, industrial or institutional use, where, at the time of the coming into effect of this Schedule or thereafter such land was zoned open space, conservation or had an equivalent zoning.
55A	The construction of facilities for the treatment of effluent, wastewater or sewage with a daily throughput capacity of more than 2000 cubic meters but less than 15 000 cubic meters

4	The construction of facilities or infrastructure for the refining, extraction or processing of gas, oil or petroleum products with an installed capacity of 50 cubic meters or more per day, excluding facilities for the refining, extraction or processing of gas from landfill sites.
5	The construction of facilities or infrastructure for any process or activity which requires a permit or license in terms of national or provincial legislation governing the generation or release of emissions, pollution or effluent and which is not identified in Notice No. 544 of 2010 or included in the list of waste management activities published in terms of section 19 of the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) in which case that Act will apply.
6	The construction of facilities or infrastructure for the bulk transportation of dangerous goods - (i) in gas form, outside an industrial complex, using pipelines, exceeding 1000 meters in length, with a throughput capacity of more than 700 tons per day; (ii) in liquid form, outside an industrial complex, using pipelines, exceeding 1000 meters in length, with a throughput capacity more than 50 cubic meters per day; or (iii) in solid form, outside an industrial complex, using funiculars or conveyors with a throughput capacity of more than 50 tons day.
27	The construction of facilities for the treatment of effluent, wastewater or sewage with a daily throughout capacity of 15 000 cubic meters of more.
Listing Notice 3	Activity
10	The construction of facilities or infrastructure for the storage, or storage and handling of a dangerous good, where such storage occurs in containers with a combined capacity of 30 but not exceeding 80 cubic meters. 'sub-criteria for each province applies'

Table 7: List of activities triggering an EIA
(adopted from DEA, 2013).

A waste management license may also be required for a waste to energy project, below is a summary of the relevant activities which triggers the need for such, adopted from the *National Environmental Management: Waste Act (NEM: WA) No. 59, of 2008 and the NEM: WAA of 2014*, and The Waste Management Regulations (GN No. 718), of 2009. An application and assessment for a waste management license can be coupled with the environmental assessment.

Category A	**Activity**
2	The sorting, shredding, grinding, crushing, screening or bailing of general waste at a facility that has an operational area in excess of 1000m2.
5	The recovery of waste including the refining, utilization, or co-processing of waste in excess of 10 tons but less than 100 tons of general waste per day or in excess of 500kg but less than 1 ton of an internal manufacturing process within the same premises.
6	The treatment of general waste using any form of treatment at a facility that has the capacity to process in excess of 10 tons but less than 100 tons.
7	The treatment of hazardous waste using any form of treatment at a facility that has the capacity to process in excess of 500kg but less than 1 ton per day including the treatment of effluent, wastewater and sewage.
12	The construction of a facility for a waste management activity listed in Category A of this Schedule (not in isolation to associated waste management activity).
3	The recovery of waste including the refining, utilization, or co-processing of waste at a facility that processes in excess of 100 tons of general waste per day or in excess of 1 ton of hazardous waste per day, excluding recovery that takes place as an integral part of an internal manufacturing process within the same premises.
4	The treatment of hazardous waste in excess of 1 ton per day calculated as a monthly average; using any form of treatment excluding the treatment of effluent, wastewater or sewage.
6	The treatment of general waste in excess of 100 tons per day calculated as a monthly average, using any form of treatment.
10	The construction of a facility for a waste management activity listed in Category B of this Schedule (not in isolation to associated waste management activity).

8 No. 8.1	Thermal treatment of general and hazardous waste for facilities where general and hazardous waste are treated by the application of heat at all installations treating 10kg per day of waste.
10	Animal matter processing for the rendering cooking, drying, dehydrating, digesting, evaporating or protein concentrating of any animal matter not intended for human consumption. All installations handling more than 1 ton of raw material per day.

Table 8: List of activities triggering a waste license
(adopted from DEA, 2013).

An Air Emissions License may also be required for in accordance to Categories 1 – 10 of Government Notice 893. However these are not very applicable to biogas projects since such projects aim to capture all the biogas and utilize it for energy production (DEA, 2013).

2.5. Conclusions from the Literature Review

This chapter provides with a summary of key observations to be retained from the literature review and be considered in the following chapters.

2.5.1. AD of MSW in a global context

MSW consists of the daily items that are consumed and thrown away by people in the both residential and commercial sectors (Braber, 1995). There is a direct positive correlation between MSW and population growth (Klass, 1998). There is also a correlation between MSW composition and level of income, waste in developing countries compared to developed countries tends to be denser, have higher moisture content, is lower in calorific value and have a higher organic content. (UNEP, 2009).

Traditionally, a waste management system is the system of collecting the waste and disposing it in landfills (US EPA, 2011). Landfilling is not a sustainable solution due to limited availability of land, rising landfilling costs and environmental concerns such as GHG emissions and leaching (Domingo and Nadal, 2009; Thomas, 2006). New trends in waste management systems puts landfilling as the last resort for waste disposal, under waste avoidance, re-use, recycling and energy recovery (Sakai et al., 1996, Palczynski, 2002).

In the past twenty years, developed countries have made remarkable achievements in adopting the waste hierarchy (Sakai et al., 1996; Eurostat, 2009). However waste management in developing countries has been lagging far behind with landfilling as the main MSW disposal method. Lack of environmental awareness, inadequate service levels, inefficient practises, lack of law enforcement, lack of human capacity and skills accompanied by lack of resources and lack of long term planning characterize waste management systems in developing countries (Eurostat, 2009).

Developing countries has a Higher MSW organic content and a higher density than in developed countries (Troschinetz et al., 2009; Thomas, 2006), which is associated with lower income levels (UNEP, 2009). This puts biological treatment as a better solution than incineration, for MSW energy recovery and treatment. Despite its high volume reduction, incineration is not suitable for developing countries due to its high level of complication in light of lack of skills, lack of required supporting infrastructures and industries and high capital and operational costs (UNEP, 2002; Asomani-Boateng, 1999).

Biological treatment (such as composting) and especially AD allow energy recovery from the OFMSW as well as the production of high value compost. The end energy product of AD is biogas, biogas has a high methane content, methane which is also known as natural gas, has many energy applications and therefore biogas as well (Igoni et al., 2008; Deublein & Steinhauser, 2011). Another advantages of biogas is the ability store it fairly easily (Greben et al., 2009; Igoni et al., 2008). These qualities of AD of MSW combined with the nature of MSW in developing countries and the relatively ease of operation, position it as the most recommended option for developing countries (UNEP, 2002).

AD of MSW can reduce GHG emissions in two ways, by diverting OFMSW from landfills and therefore avoiding landfill gas and by utilizing the biogas resulting from the AD process as an alternative energy source to conventional fossil fuels (IPCC, 2006).

2.5.2. AD of MSW in the South African and Cape Town context

According to the department of environmental affairs the average middle class South African produces 700 grams of MSW per average day, with an average of 40% organic content, which is mostly disposed of in landfills (DEAT, 2006 cited in Pegels, 2010). Two studies conducted in Cape Town by Jeffares&Green and IngeropAfrica (2004) and SEA and AMATHEMBA (2007) in 2004 and 2007 respectively showed that 5,900 and 6,000 tons per day of MSW was generated in Cape Town respectively (Jeffares&Green and IngeropAfrica, 2004; SEA and AMATHEMBA, 2007). Jeffares&Green and IngeropAfrica (2004) also argued that there is a direct correlation between waste generation and population growth in Cape Town.

The study by Gilbert, D.L. et al. (2014) clearly shows a high percentage of organic MSW content in Cape Town, of 27-48% which aligns well with the department of environmental affairs average. The study also shows that household waste is the largest source of MSW in Cape Town with a fraction of 38%, the study also characterized the composition of general household waste, showing a dominant fraction of 47% of organic content (Jeffares&Green and IngeropAfrica 2004). Data published by the City of Cape Town (2011) showed an increase in the household fraction of the city's MSW to 46% (CoCT, 2011).

The city of Cape Town has three landfill sites: Coastal Park Bellville and Vissershok (CoCT, 2011). Finding a new landfill cite in Cape Town that is both geologically and socially acceptable is very challenging. The option of building new landfill\s for Cape Town is also challenging due to high costs of waste transportation (SEA & AMATHEMBA, 2007). Nontangana (2011) points out that in Cape Town specifically, the large quantities of OFMSW rise a challenge to Cape Town's shrinking landfill space. Increasing dumping cost combined with low landfilling space are some of the main reasons behind Cape Town's high landfill gate fees of R333.2 per ton, which are expected to increase (Nontangana, 2011 cited from Malla L., 2011; City of Cape Town CONSUMPTIVE SOLID WASTE TARIFFS, 2014).

South Africa has an installed electrical capacity of about 45 GW, 93% of which is sourced from coal and centralized around the coal mining area – Mpumalanga. Eskom, the state owned utility provider supplies about 90% of South Africa's electricity (BP, 2013; Eskom 2014). South Africa imports most of it fossil fuels which is mainly used by its transportation sector (Merven et al, 2012). South Africa is the largest emitter of GHG in Africa, contributing over 40% of Africa's total CO2 emissions, 85% of which is attributed to the energy sector (DEA, 2009). Recent load shading and Eskom's poor financial state are few of South Africa's energy problems including but not limited to: energy security, energy poverty, negative environment impact, energy cost, etc. (Creamer Media, 2014).

Cape Town's main energy source is electricity (Ward & Walsh, 2010). Cape Town is heavily reliant on the national utility provider Eskom for its electricity supply (SEA, 2007). It is estimated that 95% of Cape Town's electricity comes from Eskom's coal fired power stations in the north (SEA & AMATHEMBA, 2007). This situation presents an environmental problem, due to the long electricity transmission distance and the associated transmission loses (Winkler et al., 2005).

South Africa has a comprehensive legislative framework for waste management, this framework includes but not limited to: NEMWA, SECTION 156(1) (a) and 152(1) of the Constitution, The Municipal Systems Act 2000 and the Polokwane Declaration. However waste the implementation of management systems in South Africa is very limited, mostly due to: the lack of waste information systems, rising costs, limited revenue, lack of long term waste planning, lack of waste management knowledge and training, lack of waste management capacity and lack of access to adequate funding from National Treasury (Mannie, N.M. and Bowers, A., 2014).

The energy situation in Cape Town coupled with the high quantities of MSW and its high organic content and the challenges of landfilling, position AD of MSW as desirable solution.

Cape Town has recently given priority to waste to energy integration in its waste management systems. The executive mayor of the City of Cape Town recommended that waste to energy technologies will be investigated and incorporated in support of the council's energy policy and targets, a high priority was given to the OFMSW (CoCT, 2011).

In South Africa, AD technology can be found in part of the country's waste-water treatment plants to treat and reduce the amount of sludge. Most of the AD plants in South Africa are over capacitated, not properly operated, and the biogas is often ventilated or in the better cases flared (Snyman et al., 2006; Ross et al., 1992).

2.5.3. Important parameters of AD

The process of AD is the biodegradation of organic materials, in the absence of oxygen, by anaerobic bacteria. The results of the process are biogas rich with methane (typically 50-70%) and sludge. Methane has a high calorific value and is commonly mined as natural gas as an energy carrier, therefore the biogas can be used as a renewable energy source, the sludge has a high nitrogen, carbon and other plant nutrition values and can be used as an organic fertilizer (Ahring, Birgitte K, 2003).

Anaerobic digestion (AD) is a well-established technology. Artificial or industrialized AD process takes place in a digester or reactor (Wilkie et al., 2008). AD can be broken down into four main phases that accurses in the following order: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Deublein & Steinhauser, 2011).

The main types of anaerobic digestion systems are: single or multi stage, dry or wet, mesophilic or thermophilic and batch, semi batch or continues. Choosing the digester type it typically a function of budget, application, available space, size\throughput\organic loading rate, type of feedstock and its characteristics such as total solids, volatile solids, carbon to nitrogen ratio, etc. (Chynoweth, David P et al., 2001). Mesophilic AD is the most practiced and recommended type of AD, mainly due its process stability combined with relatively high biogas yield and waste stabilization (Tchobanoglous et al., 2003; Igoni et al., 2008; Karagiannidis et al., 2009).

The biological process is the main driver of AD, therefore the symbiotic activity of the different bacteria is essential for the process stability, therefore process indicators and parameters influencing it, must be carefully monitored and managed (Greben et al., 2009). The most important process indicators are: amount of dissolved H2, PH level and volatile fatty acids concentration. Biogas yield in another important process indicator though its response time can sometimes be too slow (Boe et al. 2010). The most important process parameters to be managed are: mixing, temperature, PH level, carbon to nitrogen ratio, retention time (solid and liquid) and organic loading rate (Chynoweth et al., 1987).

The most common AD process inhibition results from the faster processing rate of the first two AD stages – hydrolysis and acidogenesis, versus the latter two - acetogenesis and methanogenesis, this is especially evident with easily fermented, carbon reach feedstock's, such as food waste. With such feedstock's, the fast hydrolysis step leads to accumulation of intermediate products such as VFAs, which leads to a PH drop and process inhibition. Hydrolytic and acidogenic bacteria are relatively pH-insensitive while methanogenic archaea only favour natural PH levels. In a well operated AD system the activity of the different microbial groups is balanced and the PH level is self-stabilizing (Igoni et al., 2008; Ward et al., 2008; Chynoweth et al., 1987).

3. Methodology

This chapter discusses the methodology used to conduct this study and answer its key questions. This chapter is broken down into 4 main subsections: technical, economic and feasibility, environmental and GHG emission reduction.

In carrying out this study, first a site audit was conducted at AF, for the purposed of collecting on site data and interviewing AF stakeholders. The information collected was used to identify the most suitable MSW AD to energy generation scenarios for AF. With Anaergia Africa support, technical aspects, design and costs were determined for each scenario. With Chand Environmental Consultant support, the legal requirements for the Atlantis project implementation were determined.

An Excel model was developed, to test the feasibility of the technical and economic aspects of the project. The information gathered for each project scenario was fed into the model and key technical and financial indicators for each scenario were compared. Sensitivity analysis were conducted on the models to test its results and better evaluate the different scenarios.

3.1. Scenarios

The chosen waste to energy scenarios considered in this study were selected according to the following methodology:

- Audit of AF electricity demand profile in the past and present and project its future demand (see section 4.1.5).
- Audit of AF electricity tariff structure and its impact on AF electricity cost (see section 4.1.5.4.)
- Assessment of the amount and quality of waste available to AF's waste to energy project (see sections 4.1.8. and 4.1.9.).
- Discussion with AF and Anaergia engineers, considering the above, to choose six scenarios to be studied and compared.

These scenarios were used to test the hypothesis that larger waste to energy projects that are established to provide attractively priced electricity provide better financial performance and that additional revenue and project viability can be strengthened by utilising excess heat streams in a combined heat and power configuration. The scenarios basically take advantage of the electricity tariff structure and are designed to optimise the financial returns by generating power at suitable times.

The following scenarios were selected:

  - 2MW continuous
  - 3MW continuous
  - 5MW continuous
  - 5MW peak and standard
  - 5MW peak
  - 10MW peak

Where:

- Continues means 24 hours, 7 days a week generation of electricity.
- Peak and standard means generating electricity only during peak and standard tariff times.
- Peak means generating electricity only during peak tariff times.

Please see chapter 4.1.5.4. "AF electrical energy usage" and table 12 for details on AF electricity tariff structure. Since AF is projected to Eskom's Megaflex tariff structure, it pays significantly more during standard and peak times in comparison to off-peak time, this situation brought up the need to explore electricity generation during the more expensive tariff times (peak and peak and standard), under the hypothesis that such scenarios will require less waste to be processed on a continues basis, since biogas will be stored during low cost tariff times, and therefore a Capex and Opex cost reduction will be achieved, while maintaining the lion share of electricity savings and thus improving the project feasibility.

The waste to energy plant will have its own electricity requirements. This was taken into account by increasing the project size to supply its own electricity needs. This means that the 2MW scenario for example, will produce 2MW of electricity available for AF to use, while the overall installed capacity is 2.52MW, to allow 0.52MW of the required self-consumption

3.2. Technical feasibility

This subsection discusses the methodology used to evaluate the technical aspects of this study.

3.2.1. Operation & production of the AD plant

Atlantis Foundries' intense and continuous mode of operation, present a great opportunity for a renewable energy off-take. This was considered in the techno-economic model as all the renewable electricity generated is off-taken by the foundry.

The waste to energy plant operation time (hours per day and days per year), operating team and their respective salaries, as well as the O&M components and costs were identified in consultation with Anaergia and in accordance with project technical specification, and process data from existing similar operations.

3.2.2. Traffic impact of AD activities

In order to assess the traffic impact of each waste to energy scenario, each scenario's incoming and outgoing streams – i.e. incoming waste, outgoing (non-organic) digestate for landfilling and outgoing compost – were calculated in a mass and energy balance, then the respective densities of each stream were assumed based on Anaergia and Waste Man past experience and used to calculate the different streams volumes, finally a typical waste truck with a 30 m^3 capacity was used to calculate the amount of trucks needed.

We assume that about half of the trucks bringing waste in, will be able to truck waste out, and thus only the trucks coming are accounted for (this assumes the volumes of digestate are half that of incoming feedstock). Compost (organic fertilizer) was conservatively assumed to be off-taken from the project site by farmers for free and its respective traffic impact was accounted for. This calculation is shown in table 29 in section 5.1.2.

3.2.3. Point of access

The methodology used to determine the most suitable point of access to the project site was to consider and evaluate the following parameters: current purpose of access point, typical daily truck flow, existence of a weigh bridge, suitability for trucks, proximity to the waste to energy site, avoiding passing through AF inner gate (gate 5), minimal disturbance to existing operations, and costs of modifications. The results of this evaluation were discussed and agreed upon with AF and Anaergia. The results of this evaluation are presented in table 30 in section 5.1.2.

3.2.4. Heat – sand drying

Heat is one of the valuable by-products of the envisaged waste to energy project. It is generated in the CHP unit (Combined Heat and Power), using biogas as fuel. Taking into account AF process (non-electrical) heat requirements, it was identified that utilizing the excess heat from the waste to energy project, for sand drying will be a feasible option, which will improve the project business case.

Most of the heat by-product will be utilized to maintain the anaerobic digesters at an optimal mesophilic temperature of 37°C. The amount of heat required for heating the digester was calculated using a heat balance and presented in table 31.

For the purpose of this study, it was assumed that excess heat from the CHP unit, not utilized for heating the digester, will be utilized in the form of hot air to replace the electric sand drying. In order to quantify this amount of thermal energy, the amount of thermal energy currently consumed by AF sand drying plant is calculated in section 5.1.4. and used as an income stream in the feasibility model.

For the purpose of this study, the chosen cost of electricity (used for sand drying) that will be replaced was set to be 0.32 R/kWh on year 0, which is the minimum cost of AF's electricity – off-peak tariff. This cost is escalating at an annual rate of 6%, reflecting South Africa's average CPI in the last four years (Statistics South Africa, 2015).

3.2.5. Electrical interconnection

The following methodology was used to evaluate the electrical point of contact, which is the interface between the supply of renewable electricity from the AF waste to energy project to AF electricity supply. First a site audit was conducted, to physically assess the current electric infrastructure and gather technical information and documentation, this information was then considered in light of:

- The chosen\preferred project location (as close to the project as possible to minimize transmission costs).
- AF head electrical engineer inputs
- Anaergia head electrical engineer inputs
- AF need to have the flexibility to distribute the renewable electricity to all of its substations.

- AF critical need to be able to run its critical equipment during load shedding.

In terms of choosing if the waste to energy project will supply AF only or AF business park as well, the initial intension to focus on AF, for the waste to energy project seems prudent due to: AF average energy consumption and base load being much larger and its favourable mode of operation (continuous & energy intense), this will be further supported by information presented in the data chapter.

3.2.6. On site solid waste & the project waste

The waste to energy project will generate two types of solid waste: compost and waste for dumping. The compost will be chemically and biologically stable and rich with plants nutrition value and therefore suitable as organic fertilizer. The waste for dumping will consist of the non-organic fraction of the waste to energy plant feedstock.

During the scoping phase it was identified that about 2,300 tons per year of general waste is generated at AF. The waste to energy project waste requirements are significantly higher, therefore cost implication of purchasing less waste for the AD project or cost reduction to AF due to diversion of general waste from landfilling to the waste to energy project were excluded. AF general waste is assumed to be similar in its quality to the expected project feedstock (Pienaar, 2014), however due to the decision above not to include it in this study, this assumption was not tested.

To determine the dumping cost of the non-organic portion of the project feedstock, Vissershok landfill gate fees were considered with a 6% increase reflecting South Africa's average CPI in the last four years (Statistics South Africa, 2015). The AF project gate fee (income stream from receiving waste) were considered in consultation with AF, Waste Man and Anaergia to be Vissershok landfill gate fees less 10%. To determine the transportation cost of the non-organic project feedstock to Vissershok landfill, AF current general waste transportation costs were used. The waste related costs above are shown in chapter 4.1.9. The AF project feedstock. All waste related costs were escalated at a 6% rate in accordance with South Africa's average CPI in the last four years (Statistics South Africa, 2015).

To determine the availability of waste to the AF project, an interview was conducted with Mr. Mike Pienaar the M.D. of Wasteman.

The AF project feedstock\waste composition was determined by Anaergia's direct assessment and data base and in consultation with Mr. Mike Pienaar from Waste Man. This waste composition was then presented in the data chapter and is also compared with literature values.

3.2.7. Water and effluent

To calculate the amount of fresh water and effluent water for discharge to the municipal sewage, a mass and energy balance was made for each scenario, with the support and guidance of Anaergia (see appendix 5). The current fresh water consumption and sewage discharge amounts were obtained from AF during the scoping phase (see section 4.1.6. in the data chapter). The current AF fresh water consumption and sewage discharge were then evaluated against the chosen project scenario to evaluate its practical feasibility with this regard.

For the purpose of the feasibility study, the current AF water and sewerage discharge cost, obtained during the scoping phase were used and escalated at an annual rate of 6% reflecting South Africa's average CPI in the last four years (Statistics South Africa, 2015).

3.2.8. Process design and philosophy

The AF MSW AD to energy project process design and philosophy was done with the advice and guidance of Anaergia (Anaergia, 2014). The same process design and philosophy was used for all six scenarios with the differences being sizing and number of units\components. The detailed process design and philosophy is given in section 4.1.11. of the data chapter.

3.2.9. Lay Out design

The different AF MSW AD to energy project scenarios layouts were done with the advice and guidance of Anaergia (Anaergia, 2014). Special consideration was given to the land available, traffic, operation and cost optimization. The chosen scenario layout is presented in the result chapter while all different scenarios layout are presented in appendix 3.

3.2.10. Process flow diagram (PFD)

The different AF MSW AD to energy project scenarios PFDs were done with the advice and guidance of Anaergia (Anaergia, 2014). Special consideration was given to operation and cost optimization. The chosen scenario PFD is presented in the result chapter while all different scenarios PFDs are presented in appendix 4.

3.2.11. Mass and energy balance

The different AF MSW AD to energy project scenarios mass and energy balances were done with the advice and guidance of Anaergia (Anaergia, 2014). Special consideration was given to operation and cost optimization. The chosen scenario mass and energy balance is presented in the result chapter while all different scenarios mass and energy balances are presented in appendix 5.

The methodology used for calculating energy production from waste input is demonstrated in equations 12 and 13 below:

$$V = W * TS * VS * Y \qquad \text{Equation 12}$$

Where:
V – is the biogas volume per hour [m^3/h]
W – is the input waste flow per hour [t/h]
TS – is the input waste total solids [%]
VS – is the input waste volatile solids as a percentage of TS [%]
Y – is the biogas yield per volatile solids [m^3/t]

$E = V * CH * e * \varepsilon$ Equation 13

Where:

E- is the energy production from the CHP unit in [kWh] it can be calculated for electric or thermal energy according to Ɛ

V - is the biogas volume per hour [m^3/h]

CH – is the methane content in the biogas [%]

E – is the calorific value of methane [KWh/m^3]

Ɛ – is the CHP energy efficiency [%] a different Ɛ is used for electrical and thermal energy

3.3. Economic feasibility

The economic feasibility of each scenario was determined using a techno-economic model, specifically made for the purpose of this study. The model was filled with technical and financial inputs, described in this study and a 20 years cash flow projection was included accordingly. The financial feasibility indicators, described below, were determined and then compared with each other, in order to determine the most financially feasible scenario. All scenario model main inputs and outputs are given in appendix 7 and all scenarios cash flow projections in appendix 6.

A large scale AD waste to energy project, like the Atlantis project, has revenues and costs, the initial costs of construction are considered high. Therefore, the project must be financially feasible in order to attract and justify the large upfront investment. The feasibility of the project is a function of the relationship between the project revenue and costs (Deublein & Steinhauser, 2011). This section summarises the methodology for evaluating the project financial feasibility.

3.3.1. Renewable electricity price

For the purpose of this feasibility study, three weighted average electricity prices were calculated for the: continuous generation, peak and standard generation and peak generation scenarios.

The methodology used to calculate the weighted average electricity price of each scenario was to first determine the annual weighted average of the different seasonal daily tariffs (peak, standard and off-peak). Then a scenario specific tariff was calculated by averaging the respective annual average tariffs.

The electricity price annual increase was conservatively assumed to be 8%, reflecting South Africa's lowest tariff increase in the past 3 years (Eskom, 2015).

For the purpose of this feasibility study, it was assumed that the self-consumed electricity price is similar to the off-take price for all categories.

3.3.2. Project costs and revenue

Project costs are often broken into investment costs or capex (mainly comprising construction costs), and operational and maintenance (O&M) costs also known as Opex (Deublein & Steinhauser, 2011). The construction costs are the costs for building the project until commissioning stage. Construction costs typically include the cost of equipment, civil and earth work, installation, etc.

O&M costs are the costs required to operate the project on an ongoing base. Operational costs are often further broken down into fixed and variable O&M costs. Fixed O&M costs are costs that don't vary directly with variation in the project input, output and performance. Fixed O&M costs typically include land lease, insurance, basic salaries, depreciation, etc. On the other hand, variable O&M costs typically include, feedstock, maintenance, energy consumption, etc. (Amigun & von Blottnitz, 2010; Deublein & Steinhauser, 2011).

Construction costs are often not linearly proportionate to the project size, due to the benefits of economies of scale. Construction costs are often estimated based on known costs of previous projects, and are adjusted in a nonlinear way to suit the current project size (Amigun & von Blottnitz, 2010). In this study, the construction costs of the AF project were accurately estimated and provided by Anaergia, using quotations from sub-suppliers, known costs of equipment manufactured by Anaergia and the vast experience of Anaergia in previous projects (Anaergia, 2015).

Fixed O&M costs for the AD plant are given in section 4.1.10.

There are several methods of estimating variable O&M costs reported in literature, Deublein & Steinhauser (2011) suggest to use as annual variable O&M costs as follows:

- 0.5% of civil works cost
- 3% of technical equipment cost
- 4% of CHP costs
- For estimating the gas upgrading or scrubber unit variable O&M costs, Deublein & Steinhauser (2011) suggest using figure 15:

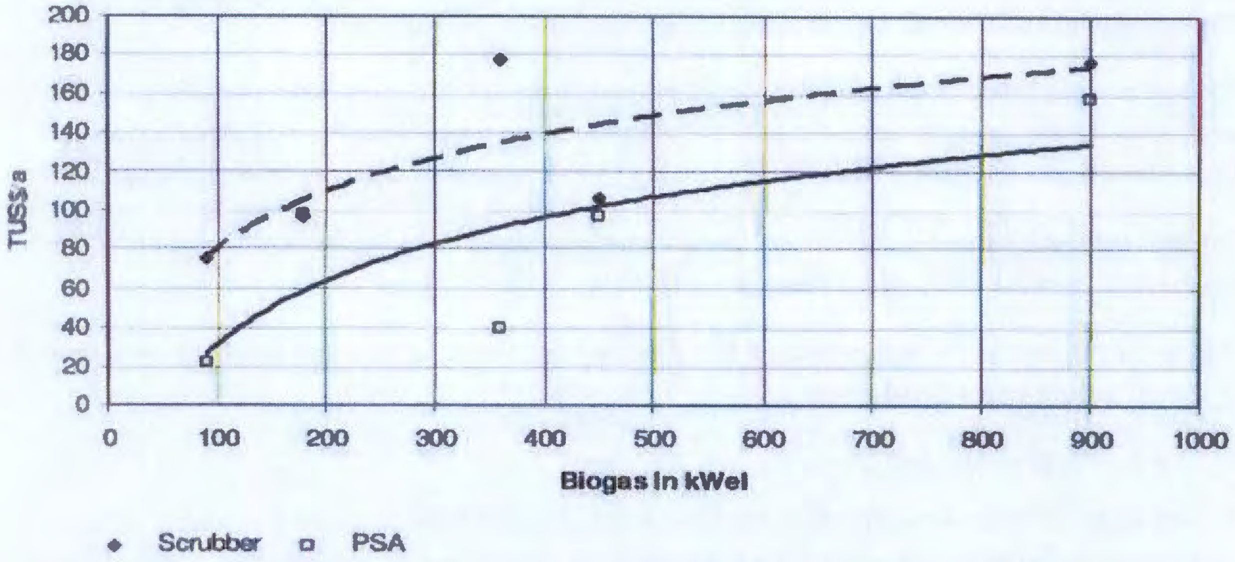


Figure 15: Gas upgrading costs as a function of biogas throughput
(adopted from: Deublein & Steinhauser, 2011)

A typical AD waste to energy project has several revenue streams, the main revenue stream is from sale of the renewable energy produced, in the form of electricity, heat, cooling, fuel substitute, etc. Other potential revenue streams are compost or organic fertilizer sale, gate fees for receiving waste, etc. (Deublein & Steinhauser, 2011).

3.3.3. Project financial feasibility

In order for any project to be financially feasible, the project costs must be balanced with revenue, any additional revenue beyond the project cost is considered profit. In order to justify the risks involved with a project and the large upfront investment, viability is a key requirement. Shen (2002) suggests three ways of evaluating financial performance of a project: time, value and rate.

Sinnott, (1999), points out that in order for a project to be viable, it must have a positive cash flow. Figure 16 below illustrate a typical waste to energy project cumulative cash flow over its life time. The cumulative cash flow is a result of the investment cost, operational costs and revenues.

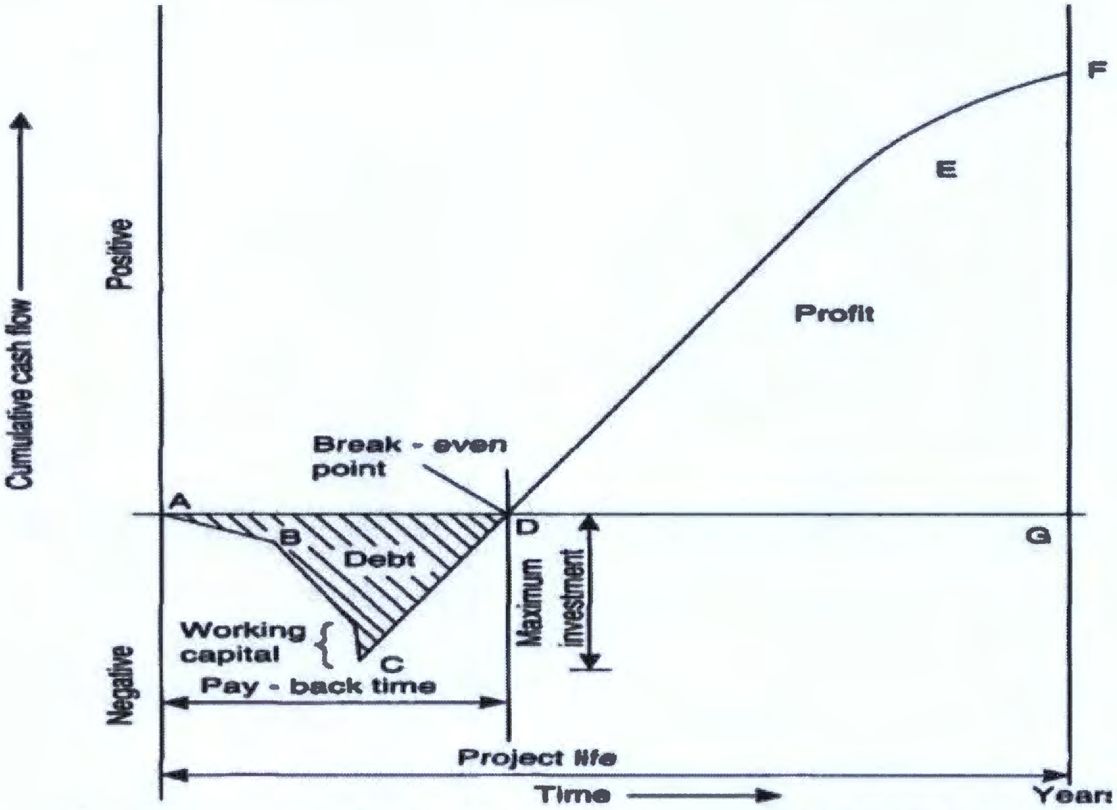


Figure 16: A typical waste to energy project cumulative cash flow over its life time (adopted from: Sinnott, 1999)

As illustrated in figure 16 above, Sinnott (1999) suggests to divide the project cash flow into five phases:

- A to B: Design phase
- B to C: construction phase up to commissioning
- C to D: the project starts operation and as a result to generate revenue. Though the project net cash flow is positive from point C, its cumulative cash flow is still negative.
- D to E: the project cumulative cash flow becomes positive, therefore point D is referred to as payback point. From point D the project is generating a return on its investment.
- E to F: The accumulation of cash is starting to slow down due to increased maintenance costs resulting from the project various components reaching the end of their life. Point F is the end of the project (Sinnott, 1999).

Though most waste to energy projects share a similar cumulative cash flow structure, they clearly differ, financial indicators such as NPV, IRR and ROI are often used to financially evaluate and compare projects (Karellas et al., 2010; Sinnott, 1999).

3.3.3.1. NPV

NPV stands for net present value, it's a value based indicator which considers the time value of money. It is calculated as the sum of discounted cash flows, over a project life time and provides an indication of the project value in today's terms. Equation 14 below is the calculation of NPV (Karellas et al., 2010):

$$NPV = \sum_{t=0}^{n} \frac{(NCF)_t}{(1+r)^t} \qquad \text{Equation 14}$$

Where:
NPV: is the net present value
NCF_t: is the net cash flow at time t
t: is the project time period (from 0 to n) in years
r: is the discount rate in %

If the project NPV is zero, then the project is at breakeven (no profits or losses), a positive NPV indicates profit. NPV is not best to be used on its own – as the only financial indicator since for example it can be positive for a project that has a negative cash flow for most of its life time (Karellas et al,. 2010).

3.3.3.2. Pay back

Pay back is the time period required to recoup the investment in the project. The shorter the pay back, the better the project. Pay back is also not best to be used on its own, since it doesn't tell anything about the project after the payback period, for example, a project can have a short and attractive pay back but overall produce losses – have a negative NPV for example (Sinnott, 1999; Perry et al., 1997).

3.3.3.3. IRR

IRR stands for internal rate of return, it's a rate based financial indicator which calculates the internal rate of return or the effective interest rate of a project, over a certain period of time. Equation 15 describes the method to calculate IRR, it is based on the NPV equation – equation 14, where the NPV is zero, meaning the net present value of the project revenue equals the net present value of the investment (Karellas et al., 2010).

$$0 = \sum_{t=0}^{n} \frac{(NCF)_t}{(1+IRR)^t}$$

Equation 15

Where:
NCF$_t$: is the net cash flow at time t
t: is the project time period (from 0 to n) in years
IRR: is the internal rate of return in %

If the IRR is higher than the project discount rate then the project is financially feasible. The higher the IRR the better. IRR is a good financial indicator for comparing different projects (Karellas et al., 2010).

3.3.3.4. ROI

Return on investment (ROI) is the average annual net profit divided by the initial investment. The ROI is an indication of the performance of the investment and is calculated according to equation 16 (Sinnott, 1999; Shen, 2002):

$$ROI = \frac{Average\ annual\ net\ profit}{initial\ investment}$$

Equation 16

Sensitivity analysis

A sensitivity analysis is also performed in this study. Its purpose is to evaluate the project financial performance or indicators, against variations in the project key parameters, for example how does the IRR changes in respect to changes in the renewable energy selling price (Sinnott, 1999; Perry et al., 1997).

3.4. Environmental\legal feasibility

The methodology followed to assess the environmental and legal requirements of the AF project was based on earlier findings by Chand Consultants, the AF project designated environmental consultancy company. Chand consultant and I conducted two site visits and held a meeting with The Department of Environmental Affairs and Development Planning (DEA&DP). Chand final report regarding the environmental feasibility of the AF project is presented in appendix 2. The findings form the basis for the environmental feasibility in this study.

3.5. Calculating GHG emission reduction

For the calculation of GHG emission reduction of the chosen waste to energy scenario, the methodology presented below was used together with calculations from the mass and energy balance. The data and assumptions used as inputs to these calculations are presented in section 4.3. of the data chapter.

The calculation of GHG emission reduction is broken down into three main parts: avoided emissions from avoided OFMSW landfilling, avoided emissions from displaced Eskom generated electricity and LPG fuel switch and emissions from biogas activity which includes biogas leakages and emissions from combustion of biogas in a CHP unit. The sum of these components represents AF GHG emission reduction, as a result of the waste to energy project.

AD of MSW can reduce GHG emissions in two ways, by diverting OFMSW from landfills and therefore avoiding landfill gas and by utilizing the biogas resulting from the AD process as an alternative energy source to conventional fossil fuels (IPCC, 2006). In order to calculate the GHG emission reduction\avoidance, the GHG emissions from the reference scenario (fossil fuel business as usual scenario) must first be calculated, then subtracted from the new activity (i.e. biogas to energy) GHG emissions (NTE, 2006).

The project carbon boundries were set around AF and therefore emissions from trucks and by product waste to be landfilled were not considered.

3.5.1. GHG avoidance from AD of OFMSW.

When OFMSW or any organic waste is landfilled, a natural AD as well as other decomposing processes accrues inside the landfill, which release landfill gas to the atmosphere, landfill gas is typically rich with methane and carbon dioxide (NCASI, 2005). Landfilling of OFMSW also produces other harmful gas and particle emissions such as volatile organic compounds, nitrogen oxide, sulphur oxide, etc. Globally in 2001 it is estimated that methane emitted from landfilling of OFMSW is responsible for 3-4% of global GHG emissions (IPCC, 2006).

In South Africa little is known about the exact landfill gas emissions and in Cape Town for example the amount of landfill gas emitted is unknown (Ward & Walsh, 2010).

According to the intergovernmental panel on climate change - IPCC (2006), two equations can be used to calculate GHG from landfilling of organic waste. Equation 17 is used to estimate the fraction of degradable organic carbon in a mixed waste stream (IPCC, 2006).

$$DOC = \sum_i (DOC_i * W_i)$$

Equation 17

Where:

DOC: is the fraction of degradable organic carbon in a mixed waste stream, measured in ton carbon per ton waste.

DOCi: is the fraction of degradable organic carbon in waste stream i.
Wi: is the mass fraction of waste i in the mixed waste stream.

It can be estimated that all the degradable organic carbon will be degraded to carbon dioxide emissions, to estimate the carbon dioxide GHG effect (Bhattacharya et al., 1997). However, since landfilling of OFMSW mainly generate methane and in light of methane's stronger GHG effect than that of carbon, equation 18 is used to estimate the amount of methane generated (IPCC, 2006):

$$CH4_{generated} = DOC * F * 16/12 * \mathrm{OX} \qquad \text{Equation 18}$$

Where:
CH4generated: is the amount of methane emissions generated from landfilling of waste, measured in ton methane per ton of waste.
DOC: is per equation 17.
F: is the mass fraction of methane in the landfill gas, multiplied by molecular ratio of methane to carbon dioxide respectively (16/12).
OX: is the oxidation factor

An oxidation factor (OX) must be considered with equation 18, since not all of the methane emissions are released to the atmosphere, as some of the methane will oxidize with the landfill soil. The OX factor is zero for unmanaged landfills that are not covered with soil and 0.1 for managed landfills that are covered with soil (IPCC, 2006). Since in Cape Town most of the OFMSW is landfilled in Vissershok and especially the designated waste for the Atlantis project, and since Vissershok is a managed landfill with soil covering (CoCT, 2011), an OX of 0.1 will be used.

3.5.2. GHG avoidance from biogas switch of conventional fuels

Utilizing biogas from AD of OFMSW as an alternative energy source to conventional fossil fuels, has the benefits of avoiding GHG emissions from the use of the conventional fuel, like natural gas, coal, diesel, petrol, HFO, etc. (Ward & Walsh, 2010). Heavy reliance on fossil fuels leads to increased levels of GHG emissions (DEA, 2009). As discussed in section 2.2, Cape Town is heavily dependent on coal generated electricity which equates to about 95% (SEA & AMATHEMBA, 2007). For the purpose of this study it will be assumed that 100% of the electricity that the Atlantis AD project will generate will replace coal generated electricity.

According to NTE (2006), equation 19 can be used to calculate carbon dioxide emissions from power generating activity (NTE, 2006).

$$CO_{2emissions} = EA * EF$$

Equation 19

Where:

$CO_{2emissions}$: is the amount of carbon dioxide emissions in kg.
EA: is the Energy activity in kWh.
EF: is the emission factor of the fuel or process used to generate the power in kg of carbon dioxide per kWh.

Letete et al (2009) calculated the emission factor (EF) for Eskom's coal generated electricity to be 1.015 kg of carbon dioxide per kWh (Letete et al., 2009).

Heating\thermal applications using conventional fuels are also responsible for GHG emissions (Winkler et al., 2005; SEA & ERC, 2010). Replacing conventional fuels for thermal application with biogas can also divert GHG emissions (Junfeng et al., 1997; Bhattacharya et al., 1997). Table 10 below shows the emission factors (EF) for both Eskom generated electricity as well as conventional fossil fuels for thermal applications (Letete et al., 2009; IPCC, 2007).

Energy source	EF	Source
Eskom generated electricity	1.015 kg CO_2 per kWh	Letete et al., 2009
HFO	21.1 Kg per GJ	IPCC, 2007
Coal	26 Kg per GJ	IPCC, 2007
Paraffin	20 Kg per GJ	IPCC, 2007
Diesel	17.2 Kg per GJ	IPCC, 2007

Table 9: Emission factors of different energy activities
(Letete et al., 2009; IPCC, 2007).

3.5.3. GHG generation from AD activities.

Finally in order to calculate the total GHG emission reduction from AD to energy activity, the fossil fuel generated emissions, should be deducted from the GHG emissions resulting from the AD to energy activity (NTE, 2006). AD to energy activities have two types of GHG emissions, unintentional methane leaks and exhaust gas from the CHP unit (NTE, 2006; IPCC, 2006).

GHG emissions from the CHP unit result from the combustion of biogas. These emissions can be calculated from equation 19 (NTE, 2006) or given by the CHP supplier, for a given biogas composition. For the purpose of this study 0.9 Kg carbon dioxide per kWh of electricity generated was used (Cuéllar, 2008).

GHG emissions as a result of unintentional biogas leaks are estimated to be in the range of 0-10% of the methane generated (IPCC, 2006). For the purpose of this study an average of 5% was used.

For the purpose of this study the system boundary of the project was around the plant and further research needs to be carried out to establish the trucks and their respective fuel use impact on the overall GHG emissions.

4. Data

This chapter presents the input data used in this study. It is divided into 3 sections – techno and economic data, environmental and legal data, and GHG emission data.

4.1. Technical and economical data

This subsection describes/presents technical and economic data used in this study. It includes a summary of the data inputs provided and gathered from Atlantis foundries (AF), during two site visits which took place on the 29/10/14 and the 5/11/14, waste related data gathered from the project designated waste supplier and Anaergia, and data concerning the operations, maintenance and design philosophy of the waste to energy plant.

4.1.1. Atlantis Foundries general background

Atlantis Foundries produces engine blocks. Basically the production process includes, melting of raw and recycled metal and casting it into sand moulds. The process is very energy intensive, the main source of energy is electricity while LPG and diesel are also used in substantial amounts, though much smaller in comparison to electricity (see more in the energy section). Figure 17 shows the picture of AF factory operations.

Figure 17: Atlantis Foundries

4.1.2. AF Operation & production

Atlantis foundries operates 24 hours per day, all week long, except for weekends when the foundry is closed from Saturday 15:00 or 19:00 until Sunday 19:00, during this time only critical equipment is on and some maintenance is done as required. The foundry is also out of operation during public holidays, though it may be in operation if demand is high, which has been the case in recent time.

Atlantis operation mode or operation hours is a function of demand, which is uncontrollable and unpredictable. Orders strategic planning is typically done 7 years in advance.

In 2014 the number of orders was significantly higher than in 2013, this can be clearly witnessed below ("electricity" section) in the foundry higher energy\power consumption in 2014 versus 2013.

The latest 7-years projection of manufacturing and respective energy consumption, done by AF is presented in the "Future energy consumption" section.

4.1.3. The site

AF is located at latitude 33°36'1.09"S; Longitude 18°28'32.55"E, in the Western Cape, Atlantis. Its altitude is about 135 meters above sea level.

AF basically consist of the foundry, where engine blocks are made ; the machining workshop, where the engine blocks are machined and warehouses that are leased out to other companies, used for storage by AF or standing empty. See Figure 18. The tenants of Atlantis are mainly industrial and engineering business. The tenants and the machining workshop energy consumption is much smaller than that of the foundry, their main energy consumption is electricity.

Figure 18: Atlantis Foundries top view
(Google Earth, 2014)

Atlantis foundries has a vacant land of about 240m * 140m or about 3.4 hectare, which is envisaged to be utilized for the waste to energy plant – it is the open space east of the foundry. See Figure 19. A second open space, West to the foundry, sized about 340m * 82m or 2.8 hectare, can also be considered for the waste to energy plant.

Figure 19: Vacant properties available for the waste to energy plant: left – eastern land; right – western land

The eastern land portion is much more flat and was pointed out by AF as more suitable for the waste to energy plant.

4.1.4. Traffic and access

Atlantis is located between the R27 to the West and the R304 to the East.

AF has 4 access points\gates marked in Figure 20 below:

Figure 20: Atlantis foundries access points
(Google Earth, 2014)

Table 11 below summarizes the gates information and typical daily trucks traffic flow. This is also shown in Figure 21.

Gate	Purpose	Typical daily truck flow
1: main foundry gate	Main entrance to the foundry	0
2: North gate	Weigh bridge gate	35
3: North gate	Main entrance to the business park	9
4: South gate	South entrance to the site	28
5: inner gate	Separating the foundry and the business park	0

Table 10: Atlantis Foundries truck's traffic summary

About 220 small vehicles access Atlantis daily.

Figure 21: AF entrance gates: from the top left corner in clockwise direction, gates 1, 2, 3 and 4

4.1.5. Energy

4.1.5.1. Electricity

Atlantis electricity supply comes from a municipal substation adjacent to Atlantis property. This municipal substation feeds in to Atlantis main substation (shown in Figure 22) which distributes the electricity to the property. Atlantis foundries electricity supply comes from 6 substations.

Figure 22: Atlantis Foundries main supply transformer

During the scoping phase, it was identified that Atlantis biggest energy consumers is its four electrical melting furnaces. Other big energy consumers include: three electrical holding furnaces, air compressors station, air extraction system, sand drying, sand mixing, sanding station and various conveyers.

The critical equipment – equipment that runs 24/7, even during load shedding are the holding furnaces, critical cooling pumps that cools the melting and holding furnaces and the foundry emergency lights.

4.1.5.1.1. Melting furnaces

The electrical melting furnaces receive raw and recycled metal and melt it while the holding furnaces keep the molten metal in a liquid form for further processing. See Figure 23.

Each electrical melting furnace have an installed power demand of 6MW. Two furnaces are fed via separate transformers and the other two share one transformer. These furnaces operate at the foundry normal operating time. During load shedding these furnaces are shut down.

Figure 23: Atlantis Foundries melting furnace

4.1.5.1.2. Holding furnaces

The electrical holding furnaces has an installed capacity of 1 MW each (three furnaces). See Figure 24. Holding furnace 1 is supplied via "West substation" while holding furnaces 2 and 3 are supplied via "G substation". These furnaces operate 24/7. During load shedding these furnaces are kept working via the diesel generators.

Figure 24: Atlantis Foundries holding furnace

4.1.5.1.3. Diesel generators

Atlantis foundries have two emergency diesel generators, which operate during load shedding or electricity supply breakdowns, to supply electricity to the holding furnaces, critical cooling systems, the foundry emergency lights and the office block. In recent years these diesel generators were hardly used due to continuous electricity supply from the utility provider, however this year there have been two load shedding already and more are expected to come in the near future.

One diesel generators is a Mitsubishi 850KW connected to "West substation" and the other is a DDC 1MW, connected to "substation G".

4.1.5.1.4. Air compressors & other loads

Other electricity loads in the foundry are: conveyers, sand mixing, sand drying, light machines, welding machines, compressors, air extraction systems, lights etc.

The air compressors system operates at the foundry normal operating hours, but often operates 24/7 to accommodate maintenance. During load shedding the compressors are turned off. The air compressors system is made of three 530KW turbine compressors and two 250 screw compressors, all manufactured by Ingersoll Rand. All compressors are connected to the same air ring and maintain a pressure of 7 bar.

4.1.5.2. Heat – sand drying

Most of AF process heating is used by the melting and holding furnaces, electricity is the primary energy source for this heat. LPG is used for process heating in a limited amount – this is discussed in section 4.1.5.8. Heat is also used for sand drying.

AF mines its own sand from a Silica sand mine nearby, the sand is than trucked to AF site, stock piled, dried, mixed with Bentonite and coal dust to form "green sand" and with a binding resin to form "coarse sand". The sand is used to prepare the molds of the engine blocks. See figure 25.

Figure 25: Atlantis Foundries sand molds

The sand drying takes place in two separate stations, old station using LPG and a newer station using electricity. See figure 26. The old station is deemed to be replaced early in 2016, with an electric drying station, which will have similar capacity and energy demand as the current electric sand drying station.

The electrical sand drying plant has an installed power capacity of 1.6MW, made of six 250KW electrical heat elements. According to production personal, this plant runs 24/7. Fresh air is sucked via fans and pass through the electrical heat elements, the hot air is then used to heat up the sand holding tank for drying.

Figure 26: Atlantis Foundries electrical sand drying plant and its heat elements

4.1.5.3. AF electrical power usage

Figure 27 and 28 show AF annual power consumption in 2013 and 2014.

The top line presents the foundry total consumption while the bottom lines presents the four melting furnaces power consumption. In both figures the X axis presents months and the Y axis demand in MW.

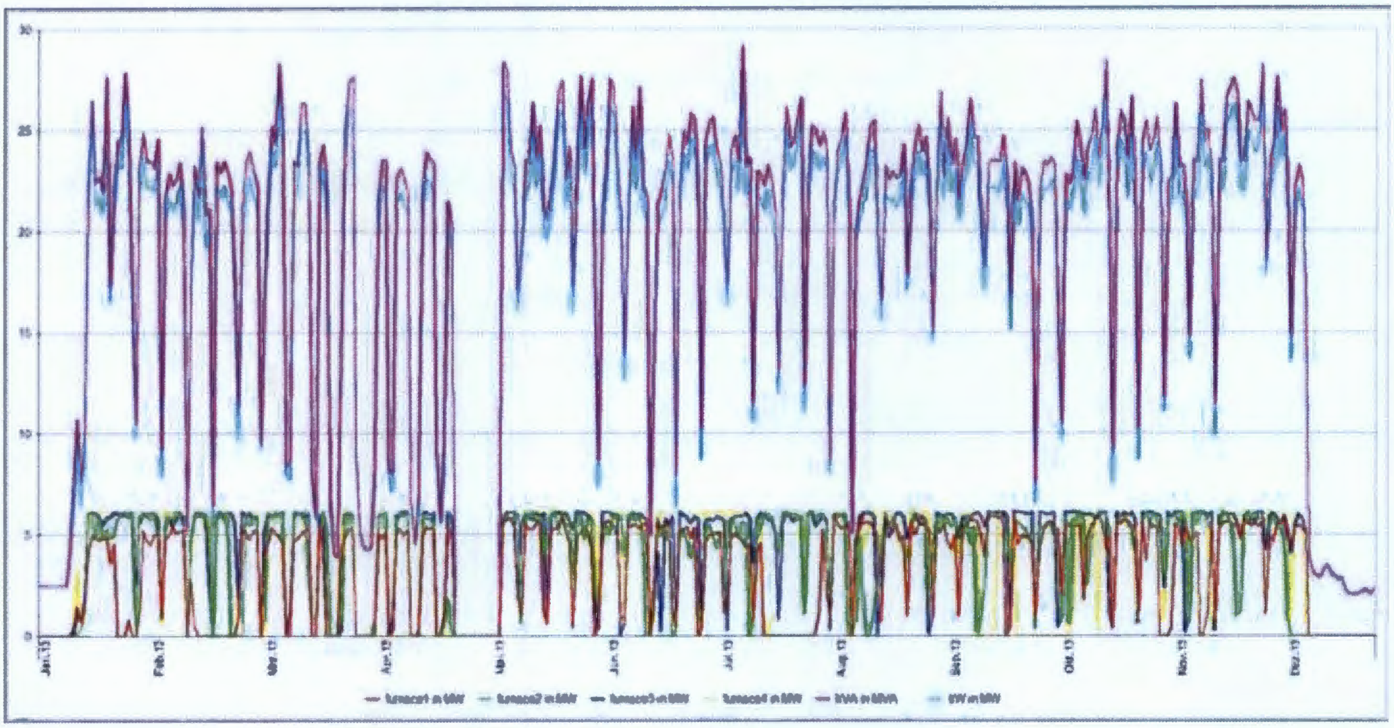


Figure 27: Atlantis Foundries 2013 power usage

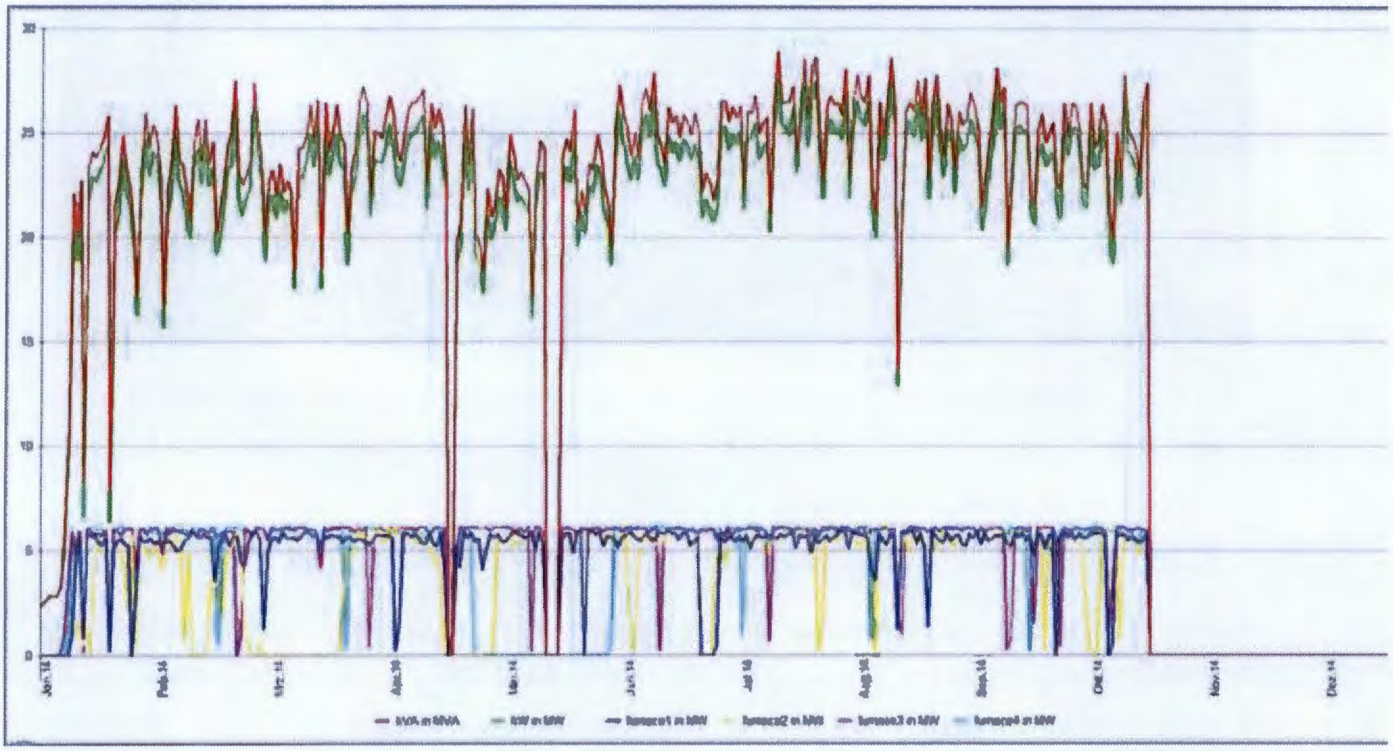


Figure 28: Atlantis Foundries 2014 power usage

It can be witnessed that each melting furnace installed power is about 6MW and that when all melting furnaces are operated simultaneously, it typically results in a total power demand peak.

The dips in power consumption are results of:

- Deliberate decrease in power consumption during peak hours.
- Maintenance \ faults.
- Weekend's \ holidays.

It can be witnessed that 2013 base load (minimum power demand) was around 5 MW with an average power consumption of 15 MW. 2014 base load and average power consumption graphs, on a monthly basis are presented in appendix 1.

From these graphs we can conclude the following:

- January's graph, shows us that the minimum power demand is during December holiday period, when the foundry is basically at an idol mode, the power consumption is about 2.5 -3 MW.
- There are two types of minimum deeps in power consumption:
  - Zero power consumption: can be witnessed mainly in April and May and a little bit in February, March and June. This is explained as load shedding or failure in the main power supply.

  - Minimum base load power consumption: of about 5MW, can be witnessed almost in all months. This is mostly a result of all four melting furnaces being off, due to production or maintenance problems.
- AF Idle mode power consumption is 2-3MW (not witnessed from the graphs but calculated with AF).
- AF base load power demand is around 10MW.
- AF average power demand is about 13-15MW.
- AF maximum power demand is about 28MW.

4.1.5.4. AF electrical energy usage

AF electricity is distributed via 9 substations, 8 of them are charged on a time of use basis and one is on a fixed tariff structure – for the office block. Atlantis Business Park is fed via two substations on a time of use base. The foundry electricity consumption is calculated as the total site consumption minus the business park consumption.

AF provided their electricity bills from 2012 to October 2014. See Figure 29. Since AF energy demand is much higher than the business park and since AF indicated that 2014 is the most representative year for electricity demand for future projections, the summary below, of AF electrical energy usage is for 2014 only.

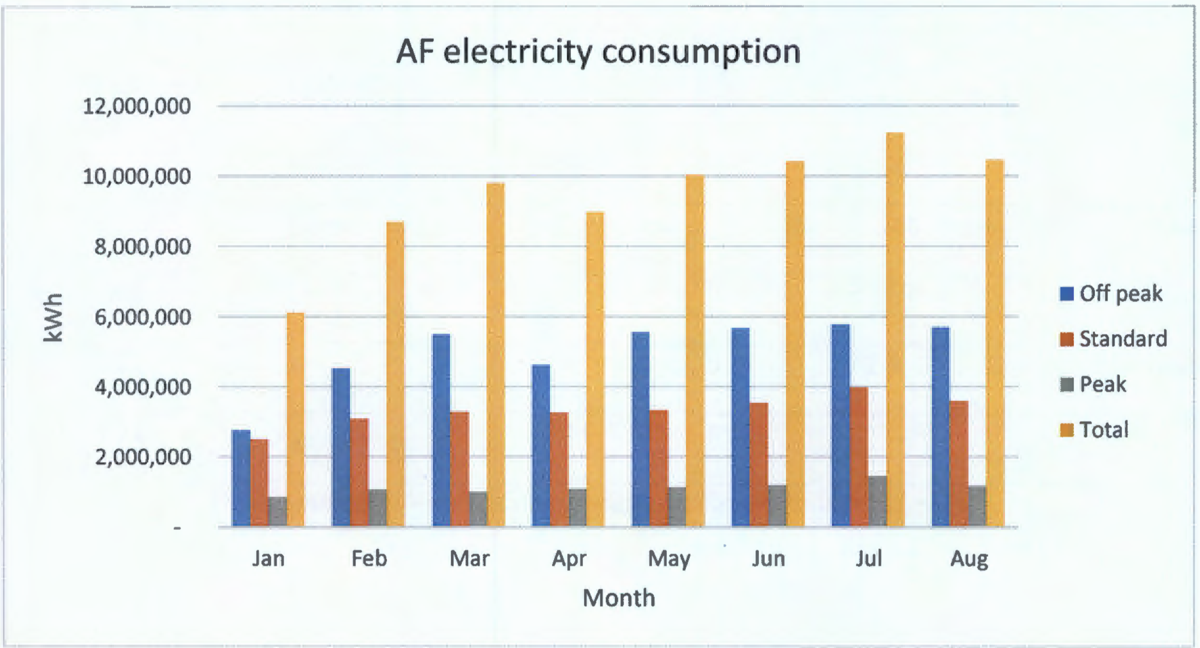


Figure 29: Atlantis Foundries electrical energy consumption over 2014

Atlantis's time of use tariff is calculated as follows, with a slight adjustment for Cape Town municipality – Saturdays are only off-peak:

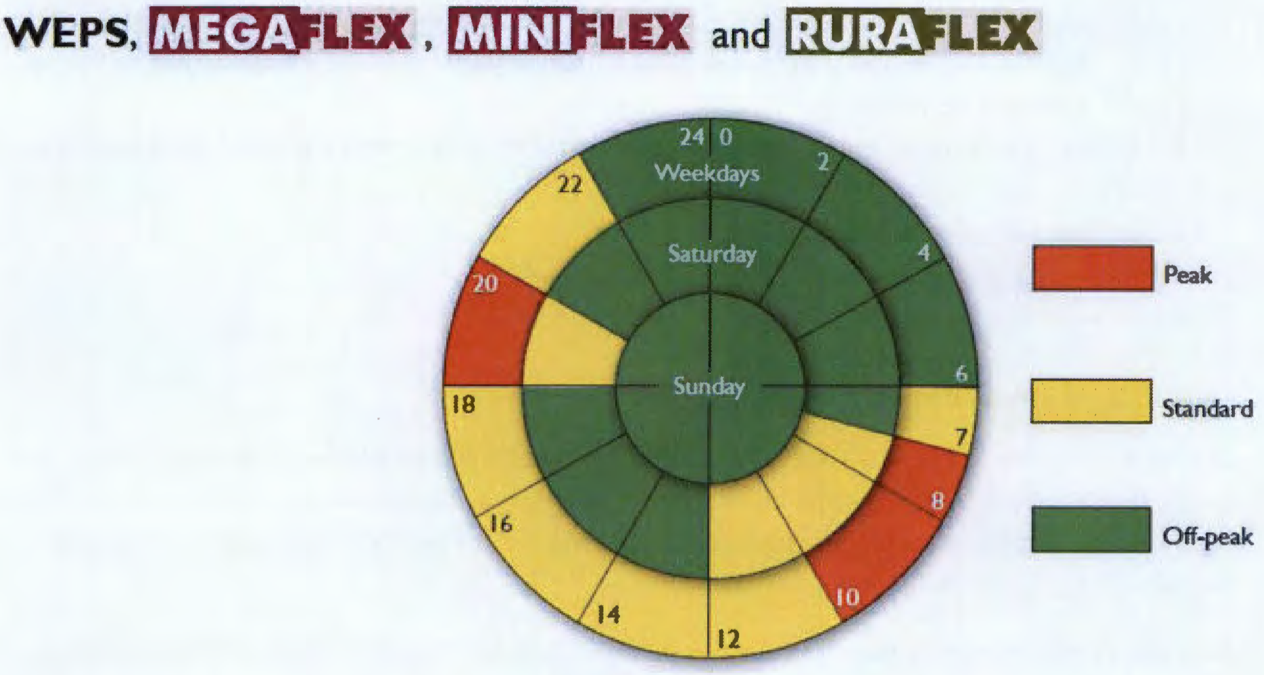


Figure 30: Eskom's tariff structure
(adopted from Eskom, 2013).

Or in another view:

Average days per month	30				Average hours per month		720
hours per	week day	Sat	Sun		month		
Peak	5	0	0		100	0	0
Standard	11	0	0		220	0	0
Off	8	24	24		160	120	120

Table 11: Eskom's tariff structure applicable to AF (Eskom, 2013)

Based on this tariff structure and the electricity bills summary the following average electricity consumptions were calculated:

	Average demand (MW)	Average electricity consumption [kWh/month]
Off peak	12.6	5,028,423
Standard	15.1	3,331,671
Peak	11 .2	1,124,450
Average\Total	13.85	9,484,544

Table 12: Atlantis Foundries calculated weighted average electricity prices (Eskom, 2013)

This calculation aligns well with the electrical power usage graphs presented in the previous section.

4.1.5.5. Atlantis business park energy usage

Figure 31 below shows Atlantis Business Park or Atlantis's tenant's energy consumption, starting from July 2013 to September 2014.

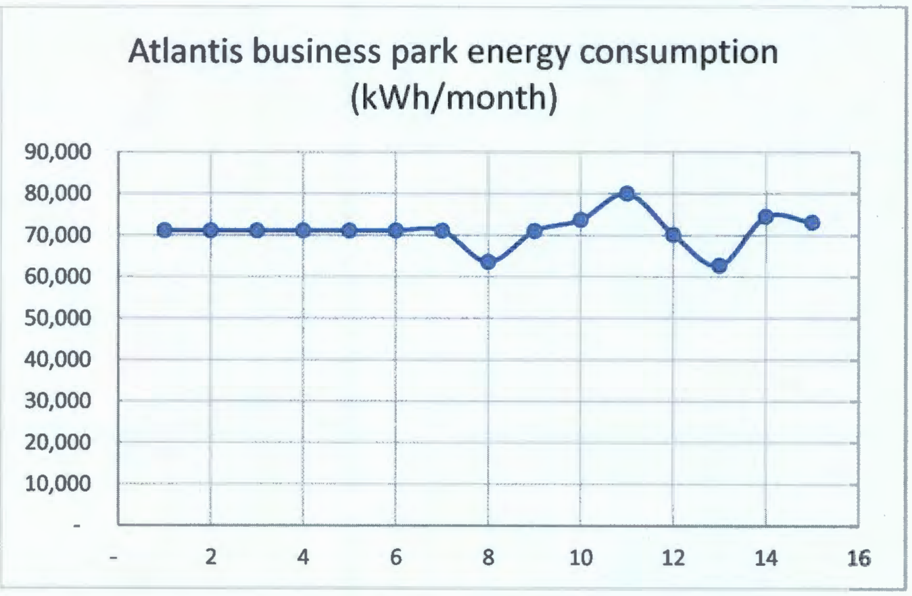


Figure 31: Atlantis Foundries business park energy consumption 2013 – 2014

It can be clearly seen that:

- During 2013, the business park energy consumption seemed to be estimated as a fixed consumption and only from February 2014 was is metered.
- A simple calculation taking an average Energy consumption of 70,000 kWh per month, and AF business park operation time of 30 days per month and 8 hours per day, shows an average power demand of 0.3 MW.

4.1.5.6. AF electricity price

AF electricity tariff structure is divided into winter and summer tariff, where the winter tariff is higher and applies between June and August (3 months of the year). AF electricity price for winter and summer 2014 was used and a weighting of 9 and 3 for the summer and winter respectively was used, to calculate the annual weighted average electricity price.

tariff	R/kWh		Annual weighted average
	Winter 14 price	Summer 14 price	
Off peak	0.3899	0.3191	0.3368
Standard	0.7129	0.45	0.515725
Peak	2.4617	0.7253	1.1594

Table 13: Atlantis Foundries weighted average seasonal electricity tariff cost (Atlantis Foundries, 2014)

For each generation scenario, a simple average of the annual weighted tariff was used, to come up with the following electricity prices (R/kWh):

Continuous	0.67
Peak & standard	0.84
Peak	1.16

Table 14: Atlantis Foundries average electricity tariff cost (Atlantis Foundries, 2014)

4.1.5.7. Future electricity consumption

Table 16 below is a 7 years projection of production and respective electricity energy consumption, done by AF:

Usage	2015	2016	2017	2018	2019	2020	2021
Total melting tons	95,269	86,527	74,312	73,344	84,603	96,654	93,270
Total Variable electricity kWh	119,086,250	108,158,750	92,890,000	91,680,000	105,753,750	120,817,500	116,587,500

Table 15: Atlantis Foundries future electricity consumption as a function of projected production (adapted from: Atlantis Foundries, 2014)

The electricity energy consumption is calculated above by AF on the basis of 1,250 kWh/ton.

AF electrical energy projections show a slight decrease in consumption between 2016 and 2018, until it peaks up again in 2019. 2020 is above 2014 and 2015 consumption, the high consumption projection continuous to 2021 and probably beyond. Even at the lowest projected consumption expected in 2018, the total energy consumption and the high base load consumption, justifies further pursue of the waste to energy project.

4.1.5.8. LPG

Atlantis receives its LPG from Afrox. Due to contractual restrictions with Afrox, the LPG price could not be disclosed and it was advised to use LPG market related price which is 21.64 Rand/Kg (SAPIA 2014), using 12.81 kWh per Kg (biomassenergycentre, 2015) yields a price of about 1.7 R/kWh. The LPG is stored in two cylinders, sized $45m^3$ and $22.5m^3$, on Atlantis site.

Atlantis foundries LPG consumption is mainly used for three applications:

a. Welding furnace: to heat engine blocks before welding (for uniform cooling). Several 150KW Thermal Jets burners are used in one furnace.
b. Melted metal bucket heating: to keep pre-casting melted metal in a liquid form in cases of load shedding or maintenance shutdowns. 1 station with one Maxon 4 inch burner.
c. Melted metal bucket coating: to dry the bucket's coating. 2 stations with no burners – air and LPG pipes are joined together and lighted manually.

The foundry LPG consumption in the last 6 months (note that the data was received on the 29/10/14):

Month	10	9	8	7	6	5	4	average
LPG monthly usage [kg]	70,900	94,940	88,400	111,640	109,060	84,400	112,140	95,926

Table 16: Atlantis Foundries LPG consumption over seven months of 2014 (Atlantis Foundries, 2014)

The locations of the different LPG stations is as follows:

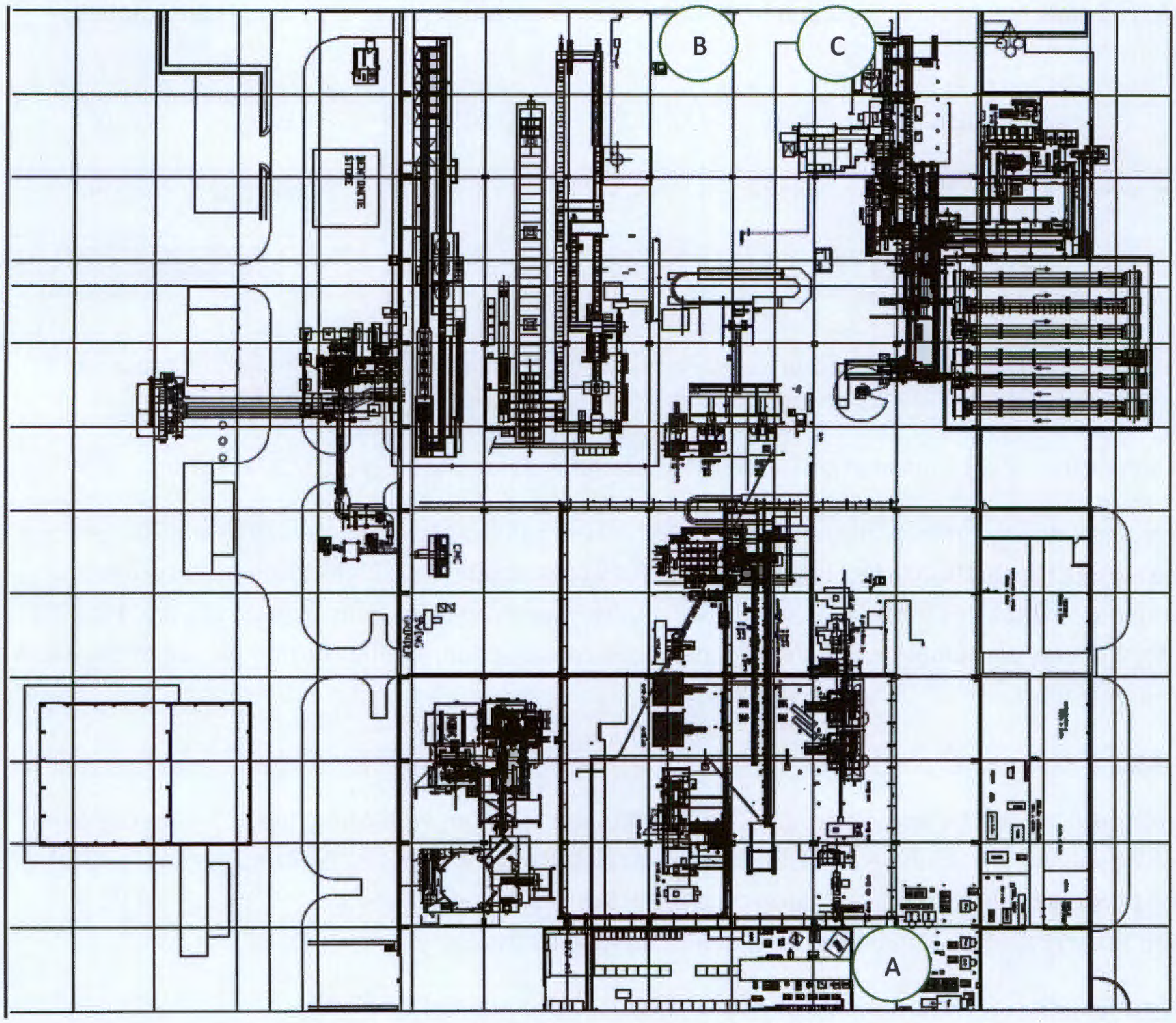


Figure 32: Location of LPG consumers in Atlantis Foundries, at A, B, and C (Atlantis Foundries, 2014)

4.1.5.9. Diesel

Atlantis foundries diesel consumption is mainly used for forklifts fueling and for the emergency generators.

The foundry diesel consumption in the last 6 months (note that the data was received on the 29/10/14):

Month	10	9	8	7	6	5	4	average
Diesel monthly usage [L]	23,258	34,392	36,461	38,723	33,669	30,575	30,633	32,530

Table 17: Atlantis Foundries diesel consumption over seven months of 2014 (Atlantis Foundries, 2014)

4.1.6. Water and Sewerage

AF uses fresh water mainly for cooling purposes and a small portion for domestic uses, while Atlantis Business Park uses fresh water for domestic uses mainly.

AF provided their municipal water and sewerage bills dating January 2012 to February 2013. The bill is separated to two water bills and two sewerage bills. It is understood that the first water and sewerage bills (the large ones) are for the foundry while the second ones are for the business park.

Figure 33: Atlantis Foundries water and sewerage usage in 2012*
(Atlantis Foundries, 2014)

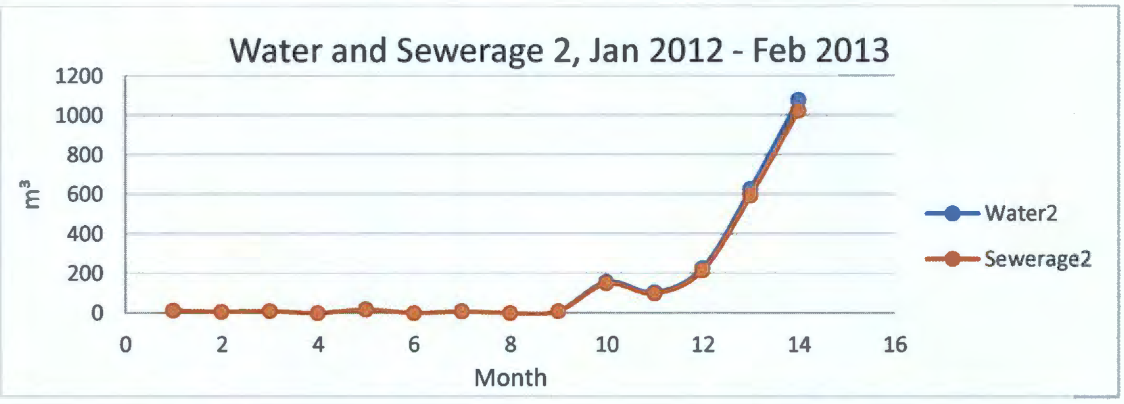


Figure 34: Atlantis Foundries business park water and sewerage usage in 2012**
(Atlantis Foundries, 2014)

* The graph U shape is a bit strange, this was raised with AF though no clear explanation was provided and therefore the data was used as received.

** The graph sudden increase is a bit strange, this was raised with AF though no clear explanation was provided and therefore the data was used as received.

The average usages are as follow:

	Average m^3
Water1	5,960
Water2	161
Sewerage1	5,662
Sewerage2	153

Table 18: Atlantis Foundries and the business park average water and sewerage usage in 2012

The fresh water cost was 9.93 Rand/m^3 and increased to 11.42 Rand/m^3 in June 2012.

The sewerage discharge cost was 7.63 Rand/m^3 and increased to 8.78 Rand/m^3 in June 2012.

The water and sewerage usage graphs show a strong correlation between fresh water usage and sewerage disposal, meaning that almost all the fresh water used are disposed to the sewerage with very little loses.

AF sewerage discharge limits must comply with schedule 1 of the city of Cape Town waste water and industrial effluent by-laws (2013), shown in table 20 below:

Section A: General		Not less than	Not to exceed
1	Temperature at point of entry	0 °C	40 °C
2	Electrical conductivity at 25 °C		500 mS/m
3	pH Value at 25 °C	5.5	12.0
4	Chemical oxygen demand		5 000 mg/l

Section B: Chemical substances other than heavy metals – maximum concentrations		
1	Settleable solids (60 minutes)	50 ml/l
2	Suspended solids	1 000 mg/l
3	Total dissolved solids at 105 °C	4 000 mg/l
4	Chloride as Cl	1 500 mg/l
5	Total sulphates as SO_4	1 500 mg/l
6	Total phosphates as P	25 mg/l

7	Total cyanides as CN	20 mg/l
8	Total sulphides as S	50 mg/l
9	Phenol index	50 mg/l
10	Total sugars and starches as glucose	1 500 mg/l
11	Oils, greases, waxes and fat	400 mg/l
12	Sodium as Na	1 000 mg/l

Section C: Metals and inorganic content – maximum concentrations **Group 1**		
1	**Total** iron as Fe	50 mg/l
2	**Total** chromium as Cr	10 mg/l
3	**Total** copper as Cu	20 mg/l
4	**Total** zinc as Zn	30 mg/l
Total collective concentration of all metals in Group 1 shall not exceed 50 mg/l		

Section C: Metals and inorganic content – maximum concentrations **Group 2**		
5	**Total** arsenic as A	5 mg/l
6	**Total** boron as B	5 mg/l
7	**Total** lead as Pb	5 mg/l
8	**Total** selenium as Se	5 mg/l
9	**Total** mercury as Hg	5 mg/l
10	**Total** titanium as Ti	5 mg/l
11	**Total** cadmium as Cd	5 mg/l
12	**Total** nickel as Ni	5 mg/l
Total collective concentration of all metals and inorganic constituents in Group 2 shall not exceed 20 mg/l		

Table 19: Atlantis Foundries sewage discharge limits
(adopted from: The city of Cape Town waste water and industrial effluent by-laws - schedule 1, 2013).

For the purpose of the feasibility study, the current water and sewerage discharge cost were used: 11.42 Rand/m^3 and 8.78 Rand/m^3 respectively (Atlantis Foundries, 2014), in year 0, escalating at an annual rate of 6% reflecting South Africa's average CPI in the last four years (Statistics South Africa, 2015).

4.1.7. Cooling

AF uses a large portion of its fresh water for process cooling. The cooling is mainly done on the furnaces, machinery, sand (after heating for drying), air compressors, transformers and other small uses. The operation and maintenance of the water cooling systems is done by a contractor called Water Cure.

There are 5 areas around the foundry where cooling is done, these areas are not connected. There's a large concentration of cooling towers in the South Western corner of the foundry where 8 cooling towers are located and connected together. According to Water Cure, Atlantis's cooling system has a lot of leakages and large parts of it is not metered properly.

According to Water Cure the cooling water requirements are:

- TDS: 800 – 100 (some of the cooling towers have a TDS sensor which discharges the water once reached 800 TDS)
- Magnesium & Calcium PPM: 35 – 36
- PH: 7.8 - 8.2
- Nitrogen: should be low as possible to prevent bacteria growth.

Table 21 below is a summary of all cooling towers and their water consumption in m^3, from January to October 2014:

Cooling towers	1-10/14 water consumption m^3
ABB 4 Furnace	1301.92
ABB 4 Electrics	909.74
PPF 1	804
ABB 3 Electrics	1060
Holding 3 Furnace	19
Holding 1 Furnace	133
Holding 2 Furnace	394
ABB 3 Furnace	3909
ABB 1,2 Electrics	8520
VIP	812
Old Sand Dryer - Visagie	56
New Sand Dryer - Visagie	602
Core shop and Shot-blast	333.17
COMPRESSOR HOUSE	9968
Molding Line 1 Cooling	609.45

Table 20: summary of Atlantis Foundries cooling towers water consumption (Atlantis Foundries, 2014)*

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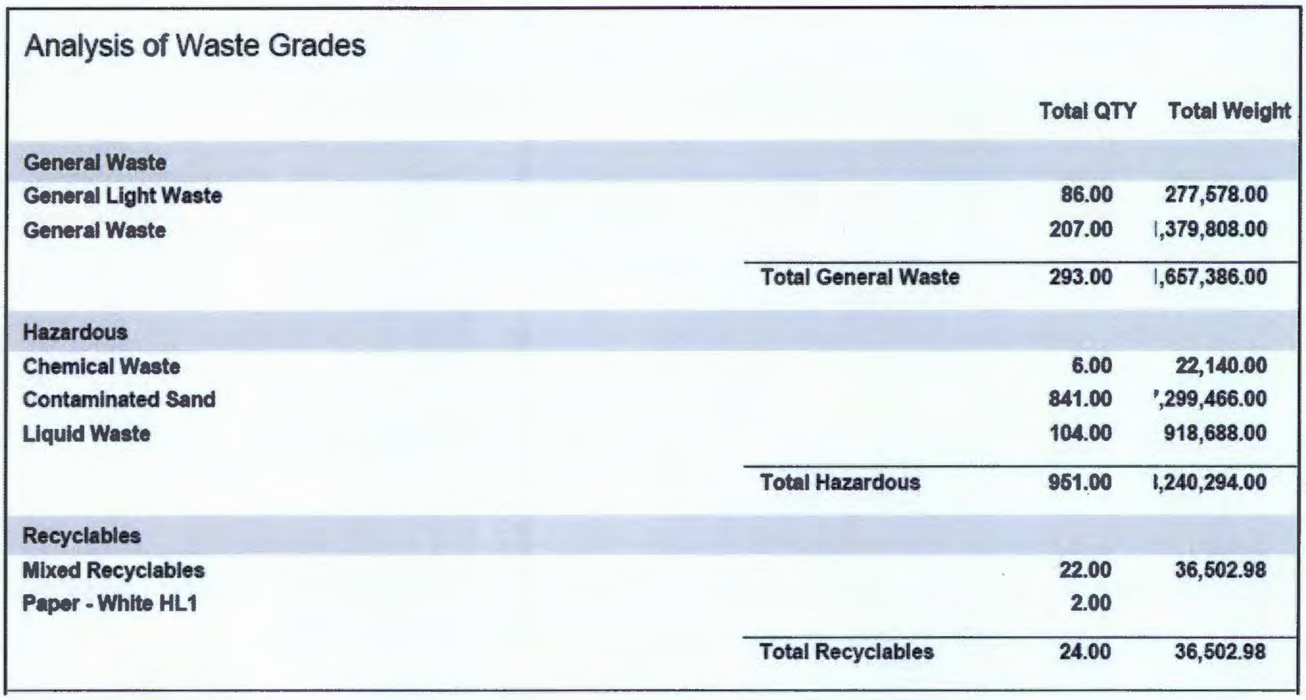
* It can be noted that there is a relatively large difference between cooling water usage and sewage, which can not clearly be related to evaporation. When addressed with AF, AF noted that some of the water meters were broken during the measured period.

The total cooling towers water consumption, January to October 2014 adds up to 29,431 m^3. The average monthly consumption is 2,943 m^3. This average is a bit below the expected, as AF average monthly total water consumption is 5,960 m^3 and it is expected that cooling water will make a larger portion of the total. However this can be explained by the fact that some cooling towers monthly water readings are zeroes – the meters are broken.

4.1.8. On site solid waste

All the waste from Atlantis site is managed (collected, disposed, managed) by a private waste management company – Waste Man.

The following is a numerical and graphical summary of Atlantis's waste, dated January to October 2013 (weight is in Kg, QTY is number of collections):



Analysis of Waste Grades

		Total QTY	Total Weight
General Waste			
General Light Waste		86.00	277,578.00
General Waste		207.00	,379,808.00
	Total General Waste	293.00	,657,386.00
Hazardous			
Chemical Waste		6.00	22,140.00
Contaminated Sand		841.00	,299,466.00
Liquid Waste		104.00	918,688.00
	Total Hazardous	951.00	,240,294.00
Recyclables			
Mixed Recyclables		22.00	36,502.98
Paper - White HL1		2.00	
	Total Recyclables	24.00	36,502.98

Table 21: Atlantis Foundries waste production summary in 2013 (Atlantis Foundries, 2014)

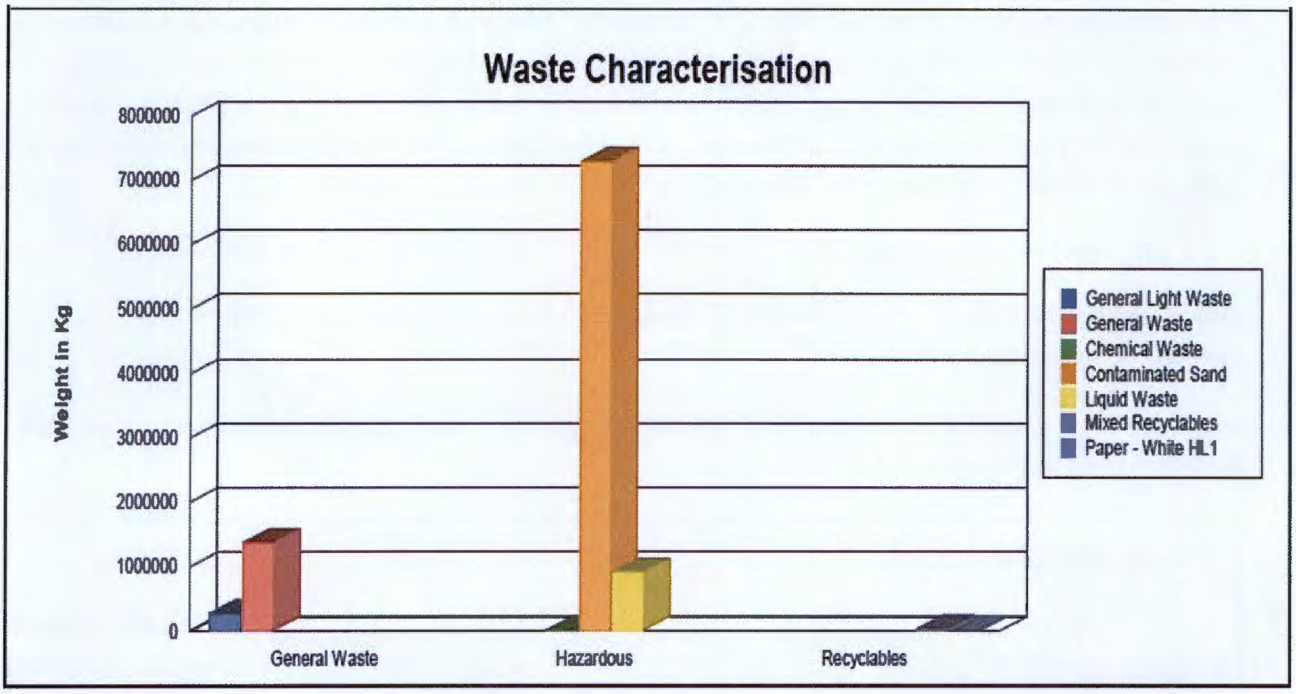


Figure 35: Atlantis Foundries waste distribution summary in 2013
(Atlantis Foundries, 2014)

The numbers above show that about 1.7 million tons of general waste was collected during January to October 2013, or about 6.3 tons per day (using 9 months and 30 days per month).

4.1.9. The AF project feedstock

AF is located about 40 Km from Vissershok landfill, a private landfill partially owned by Cape Town Municipality and partially owned by Waste Man and Enviroserve (another large private waste management company), and one of the largest landfills in the Western Cape. Vissershok landfill is at 80-90% capacity and its gate fee is 390 Rand/ton (CoCT, 2011; CoCT, 2014).

For the AF project non-organic waste portion for disposal, a conservative dumping cost of 390 Rand/ton was used plus 120 Rand/ton for transportation to Vissershok (Pienaar, 2014), at year 0, escalating at an annual rate of 6% reflecting South Africa's average CPI in the last four years (Statistics South Africa, 2015).

In terms of waste availability for the AF project, a high level meeting with Mr M. Pienaar, the M.D. of Wasteman, took place in Stellenbosch on the 14th of November 2014. Mr M. Pienaar confirmed that there is 800 tons per day of food waste, market waste and SSO (source Separated Organics), available for the project. Mr M. Pienaar also confirmed interest to supply this waste to the Atlantis waste to energy project (Pienaar, 2014). 800 tons per day is comfortably above 600 tons per day, the demand of the 5MW continuous scenario, which is the highest waste demand out of all six AF waste to energy project scenarios.

We assume the AF AD project gate fee to be 300 Rand/ton on year 0, or 23% less than Vissershok landfill gate fee. This fee is escalating at an annual rate of 6% reflecting South Africa's average CPI in the last four years (Statistics South Africa, 2015).

For the purpose of the study and basic engineering, the following waste composition was used:

Waste Composition:	Total Solids (TS)	± 44% of waste
	Volatile Solids (VS)	± 80% of TS
	Organic Fraction	± 65% of WM
	Light Fraction (paper, card, plastic, fines)	± 30% of WM
	Heavy fraction (glass, metal, textiles, stones)	± 5% of WM

Table 22: Atlantis Foundries MSW composition
(Anaergia, 2014)

This aligns well with literature data presented in figure 3: characterisation of general household waste in Cape Town, given that AF designated MSW feedstock will be mostly made of source separated organics (SSO) (Jeffares&Green and IngeropAfrica, 2004).

The compost from the project may be sold as an organic fertilizer to farmers nearby. However, we assume farmers will collect the compost for free.

4.1.10. The waste to energy plant Operation & production data

The waste to energy project will operate 24 hours a day, 7 days per week and 350 days per year (with down time accounted for). Waste will be received during normal work hours 8:00 – 17:00.

For the operation of the waste to energy plant (all 6 scenarios), the following team will be required, with the following expected salaries:

	No.	**R/month**
Supervisor	2	30,000
Technicians	2	25,000
Operator	10	5,000
Total	14	120,000

Table 23: Atlantis Foundries MSW AD plant personal and their income (Anaergia, 2014)

These salaries estimates are conservative and aligns with the offered value in the City of Cape Town's job vacancy advertisement for a senior wastewater plant operator of 80316 R/year (CoCT, 2011).

The supervisors and technicians will work 1 shift per day (one person per shift) and 1 shift standby, while the operators will work 3 shifts per day (3 persons per shift) and 1 shift standby.

Other operational expenses of the waste to energy project are:

Operational expense	Value [R/y]	Annual increase
Operation service	1% of Capex	6%
Insurance	0.3% of Capex	6%
Maintenance	3% of Capex	6%
Land Lease	0	6%
Admin fees	91,000	6%

Table 24: Atlantis Foundries operation expenses of the waste to energy project (Anaergia, 2014)

This aligns well with literature values:

Insurance	0.5% of digester capital cost per year
CHP maintenance	4% of CHP capital cost per year
Technical equipment maintenance (mechanical, piping, steel structures electrical and instruments)	3% of technical equipment capital cost per year
Concrete works maintenance	0.5% of concrete capital cost per year

Table 25: AD plant operational costs
(adopted from Deublein & Steinhauser, 2011)

4.1.11. Process design and process philosophy description

This section provides a generic description of the process flow, design and philosophy, which applies to all investigated scenarios.

4.1.11.1. Reception building

For reception and processing the waste substrate, a reception hall will be built. This building will contain the entire pre-treatment equipment consisting of a hopper, shredder, the organic extraction system - OREX press, several screws and conveyor belts and a liquid feeding pump to the AD plant. Locating all the pre-treatment equipment in one hall together with the tipping floor as storage area for the SSO facilitates the control of the solid feedstock supply. The waste materials are delivered by trucks daily and temporarily stored in the reception hall. Therefore the reception is designed to be accessible for trucks to drive in, discharge and drive out again.

4.1.11.2. Feeding hopper

The SSO will be delivered to the reception hall and fed into a hopper, then further conveyed with a double screw conveyor into an optional chipping machine (shredder).The batch feeder (Hopper) which also is placed in the reception hall is filled by wheel loader. After filling, the screw conveyors on the floor move the substrate to an ascending screw conveyor. The bunker walls and the screw conveyors are made of stainless steel, therefore the wear and tear of the solid feeder due to corrosion is minimized. On the outlet of the ascending screw conveyor the feedstock drops into the Orex press and the bag opening shredder. This process is completely automated and only needs one person to feed the substrates into the hopper.

Figure 36: Feeding hopper with double screw conveyer

4.1.11.3. Bag opening Shredder

In case the feedstock includes bigger material it can be chopped into smaller pieces by the bag opening shredder before being conveyed into the OREX press. The bag-opener can be fed by a feeding screw conveyor or directly with a wheel-loader. The material falls on a drum, this drum is equipped with hammers, which are arranged in a helical manner. The slow rotating drum takes the material along an adjustable counter plate on which robust wear-resistant counter hammers are mounted. This counter-plate can be adjusted to set the spacing between the rotating and counter hammers. A big opening will let full bottles pass the shredding drum while a small opening achieves a finer shredding. This machine is easily hydraulically opened for maintenance and cleaning purposes.

The hammers on the drum and the comb are made from Hardox, hard, wear-resistant material. It's easy to refit the hammers with a hard-facing layer without replacing the hammers. The hammers are placed in such a way that the highest rate of bags (close to 100%) will be opened. After opening the bags, the material from the bags will fall out at the bottom of the machine onto a conveyor or in a chute.

Overload door: The bag-opener is equipped with both an electric control and a hydraulic control to prevent overload. As soon as an overload occurs the feeding conveyor will stop. The drum will turn in opposite direction for some time and try again. When the blockage repeats, the machine will give a signal and the door of the machine can be opened hydraulically to remove the blockage. The closing force of the door is hydraulically adjustable. When it opens, by over-force the machine will stop without damaging. If the drum builds up with too much wrappings like plastic film, this is detected and the drum will drive backwards where a scraper will cut the wrappings. This process is fully automated. From the bottom of the shredder, the material falls onto a conveyor belt, which transports the material further to the OREX press.

Figure 37: Bag opening shredder

4.1.11.4. OREX press

The organic waste will be conveyed to the OREX Press. By applying the Municipal Solid Waste to an extremely high pressure, the organic and wet fractions are liquidised. They become soluble. This soluble organic fraction is separated from the material that is mechanically more resistant. This more resistant fraction is called the solid fraction (paper, cardboard, plastics, rubber, etc.). The soluble organic fraction is pressed through a perforation. When the compression phase is finished, a door opens. The solid fraction is evacuates sideways with the solid fraction cylinder.

The OREX press is equipped with: Pre-press flap actuated with two cylinders, the pre-press flap compresses the material up to 50%. Infeed ram with linear position detection. The infeed ram pre-compresses the material up to 50%, and brings it into the extrusion chamber.

The main extruding cylinder with a maximum thrust of 450 tons extrudes the liquefied material from the infeed material. The hydraulic pressure of the return stroke can be increased to create higher return force on the cylinder. This main cylinder is equipped with linear position detection for accurate functioning. The remaining structural material will be ejected from the extrusion chamber with the solid fraction ram after opening the door. The channelled extrusion plates can be exchanged. The extrusion chamber has fully exchangeable wear plates on all sides. The (extrusion) rams have exchangeable wear-plates to increase the lifetime.


Figure 38: OREX press


Figure 39: Solid fraction


Figure 40: Organic fraction

4.1.11.5. Conveyer belts, screw conveyers, access platforms and stairways.

The feedstock and the different process streams will be transferred through the waste to energy plant via belt and screw conveyers (i.e. the organic fraction from the press will be conveyed by a screw conveyer into a mixing pump).

Steel structures, stairways and platforms will be used to allow safe accessibility to the different waste to energy plant components, for O&M purposes.

Figure 41: Example Stairways and Platforms

4.1.11.6. Mixing pump

The final mixture will be pumped by a mixing pump from the bunker into the anaerobic digestion tanks - in case of necessity liquid digestate or fresh water might be added in this mixing pump for dilution.

The pump housing has a large rectangular hopper and removable conical force-feed chamber, as well as a coupling rod with patented, horizontally positioned conveying screw, this guarantees an optimal product feeding to the conveying elements.

Figure 42: Example Mixing Pump

4.1.11.7. Triton® anaerobic digester

The anaerobic digestion of the feed is carried out within a triton digester, which is completely mixed mechanically with stirrers installed on the roof of the digester.

Thermal energy consumption of the plant is minimized by the patented ring-in-ring Triton® system of Anaergia. In this system the fermented substrate in the digester (outer ring) is conveyed into the inner ring, therefore the heat loss of the secondary digester due to the lateral surfaces is equal to zero. The concrete roof of the triton tank of the outer ring is another advantage of reducing the thermal losses.

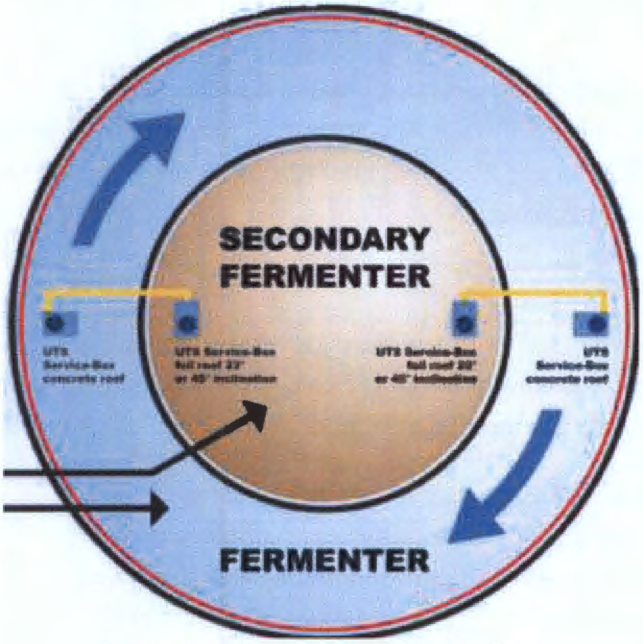


Figure 43: Triton® system illustration

The digesters are operated at mesophilic conditions at a temperature of 38 – 42 °C. At this temperature range inhibition of biological activity caused by ammonium or H_2S can be avoided. As the aim of this biogas plant is to produce bio methane for a CHP plant, the required heat for the mesophilic media in digester tanks is fulfilled by a gas burner or electric boiler. To assure a high biogas production the hydraulic retention time of input feed is approximately 30-40 days.

Due to above mentioned advantages, a concrete Triton® digester has been designed with an outer ring with a large capacity and an inner ring. Both, digester and secondary digester have their mixing system, which are equipped on the tank walls. The mixers and their specifications can be found in the next section.

The following descriptions follow the anaerobic digestion process: the produced gas will be collected in the membrane roof of the secondary digester. From there the gas will be extracted into an optional external biological desulphurization facility. Afterwards the biogas conditioning will take place.

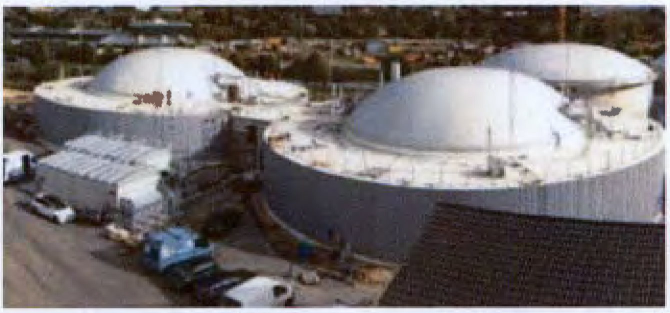


Figure 44: Triton® system picture

The input of the substrate to the digesters is automated based on a pre-set volume on an hourly basis as well as on the available incoming substrate. The volume of substrate transferred to the digester is monitored by means of a flow meter. The plant operator maintains control of the substrates added to the digesters to ensure optimal operation efficiency.

4.1.11.8. Mixing technology

Powerful electrical mixers are installed to mix the digester content thoroughly. Fresh material is mixed with bacteria-rich digestate. Biogas can strip out easily in well and fully mixed digester.

Anaergia S.M.A.R.T mixing system: The automatic mixing control optimizes the mixer´s performance according to changing operation modes. Depending on the priorities set (operation modes such as "mixing in fresh substrate", "mixing the fermenter content" or "controlled gas desorption from lower tank areas"), the system takes care of the most efficient operation of the mixer based on the permanent collection of measuring data via the fully automated control unit. This results in remarkable reductions in costs for maintenance and energy consumption of mixers as well as a substantial increase in operation safety and reliability. This unique product enables biogas plant operators to fully exploit the biogas potential with regards to flexibility, both regarding modification in substrate intake (e.g. biomass to wastes) as well as energy production (flexible power input).

Figure 45: Electrical Mixer

The mixers are height adjustable using steel guiderails. Floating layers can therefore easily be prevented.

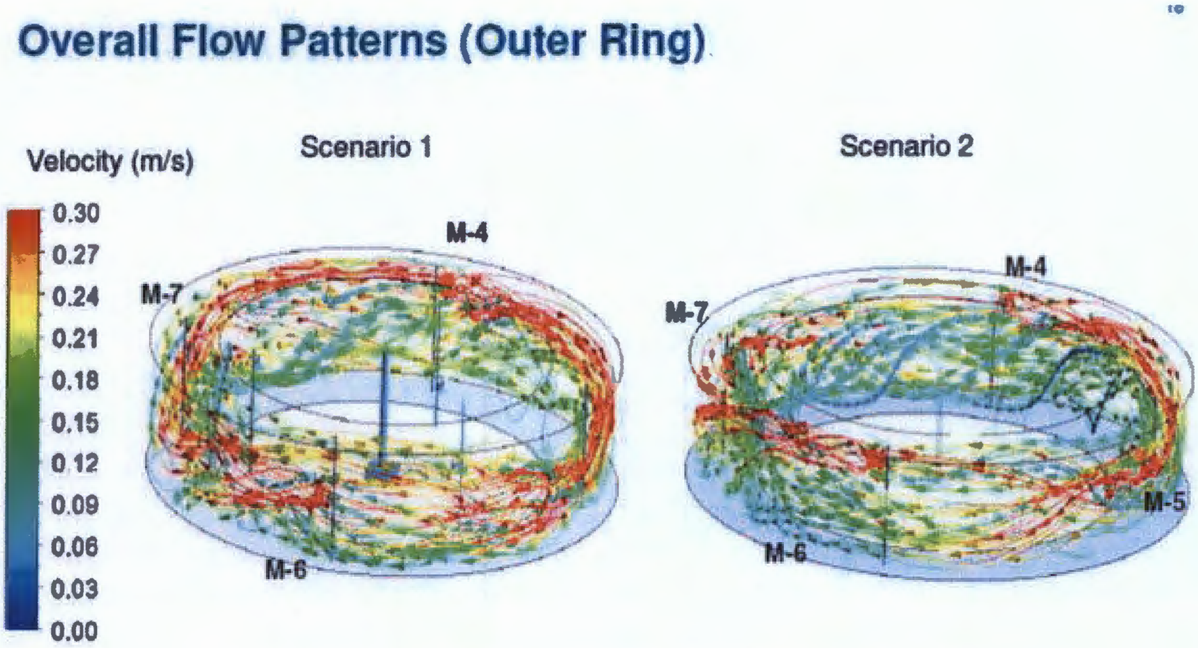


Figure 46: Anaerobic digester flow patterns (Anaergia, 2014)

The 12,5kW drive transfers enough power to the 3-bladed mixer to move the material. Once the material is in movement the absorbed power drops. The mixers can be run continuously or intermediate on demand and controlled by a PLC.

4.1.11.9. Service box

The Anaergia patented Service Box enables easy and safe maintenance of the electrical mixers. This enables easy access to the digester inside without major biogas losses.

Additionally the under-pressure and overpressure safety devices are integrated in the service boxes. They consist of gas-tight welded boxes that are attached to the cover plate of the service box by screws. The connections from the inside of the fermenter to the discharge flue of the overpressure safety device and from ambient atmosphere to the inside of the fermenter for the under pressure safety device, are interrupted by weight-loaded immersion cups that are raised by the respective gas pressure and allows pressure-regulated gas to pass through.

Figure 47: Service Box

4.1.11.10. Membrane foil roof

Biogas produced in the digesters is captured in the headspace between the top of the liquid in the secondary fermenter and the double membrane gas holder cover installed on the inner ring. From this point the gas is drawn off and transferred to the external biological desulphurization system. The gas holder membrane is a two-layer tensile fabric, which accommodates the Anaergia digester mixer service box. The outer weather resistant layer of the membrane is supported by a continuous flow of air supplied by an air blower; this gives the outer layer the strength against weather conditions and holds the system pressure at the inner layer. The inside layer acts to retain the biogas and moves up and down according to the volume of gas in the digester headspace.

A biogas blower is used to transfer the biogas stored in the digester headspace under the membrane gas holder cover to the optional external biological desulphurization system or to the emergency flare.

The gas produced in the primary fermenter is piped to the secondary fermenter where it mixes with the gas produced in the secondary fermenter.

Figure 48: Membrane foil roof

4.1.11.11. Gas storage

The produced biogas is captured in an external double membrane gas holder. From this point the gas is drawn off and transferred to the gas utilization equipment of the plant. The gas holder membrane is operated on the same principle as the membrane foil roof described above.

Figure 49: External double membrane gas storage

4.1.11.12. Gas flare

In case of excess biogas production or standstill of the gas consumers, excess gas can be flared. The flare is equipped with a blower, condensate trap, flame monitoring, non-return valve and flame arresters. Flare ignition is automatically controlled and the flare is designed to meet stringent emission standards.

Figure 50: Gas flare

4.1.11.13. Gas cooling

The gas cooling equipment dehumidifies and dries the biogas for subsequent use in biogas upgrading unit. Benefits of gas cooling are: reduction of plant downtimes and increase operating safety and optimal conditioning for further cleaning step, activated carbon filter. Dehumidification of the gas is performed according to the condensation drying principle. Gas cooling takes place in water cooled shell and tube heat exchanger. By cooling the gas flow, water condenses and is removed from the gas. Accumulated condensate can be discharged by using a condensate collection tank with level control and controlled electric valve.

Figure 51: gas cooling

4.1.11.14. Active Carbon Filter

The active-carbon filter unit is constructed redundant and removes all indicated contaminations like H2S and other sulphur compounds. Other components which might be eventually in the biogas have not been taken into consideration of course. The unit consists of four filter boxes where three of the boxes are in use constantly. Whenever a change of the unit is necessary due to saturation this displayed to the control system operating screen and the unit is switched to one of the other operational filters so that the CHP remains fully functional. The housing of the plant is constructed with a rolling shutter gate so that the saturated units can be removed by a fork lift without any further effort and the change can be implemented on site.

Figure 52: Active Carbon Unit

4.1.11.15. Ferric chloride dosing station

For desulphurization, a ferric chloride injection system is installed. In order to reduce the H2S concentration of the biogas, ferric solution is added to the substrate. This unit consists of a storage tank including a discharging diaphragm pump and a control unit. It can be chosen if this system shall run automatically time controlled or manually.

Figure 53: Ferric solution- Dosing station

4.1.11.16. Combined heat and power (CHP) system

A Gas engine coupled to brushless self-exciting alternator wound for a supply of 400V @ 50Hz and 1pf. The generator is mounted on a steel base frame coated in corrosion resistant paint.

Figure 54: CHP

4.1.11.17. Mechanical Build:

The gas generator will be supplied with the following equipment in order to ensure reliable and safe operation:

- Zero pressure gas train
- Cooler circulating water pumps
- Three way control valves
- Expansion vessels
- Differential pressure monitors
- Starter Batteries

4.1.11.18. Exhaust:

Each generator will be supplied with a loose 3CR12 stainless steel silencer. The silencer will be designed to limit operation noise to an estimated 85 dB at 10 meters.

4.1.11.19. Heat Exchangers:

The generator will be supplied with a plate heat exchanger sized for the rated thermal output.

4.1.11.20. Table Coolers:

Each generator will be supplied with two table coolers designed to provide maximum cooling in the event that the heat is not harvested completely. The table coolers will be designed for floor mounting outside the plant room and will be force cooled by induction driven fans.

4.1.11.21. Switchgear:

The generator will be supplied with a low voltage motor control panel. The panel will control all generator interfaces and start and stop the various motors as required. The control will include the following starter circuits: ccirculating pumps, radiator fans, after cooler fans and oil pumps.
A generator control system will be capable of monitoring and controlling all the generator functions. A control PLC will be supplied with a generator SCADA system to monitor generator operational functions.
The MV switchgear suite will consist of the following: 4 generator incomers, two plant Feeders, one auxiliary transformer feeder, one battery tripping unit, bus section and a riser.
As part of the electrical system a suitably rated auxiliary transformer and generator step up transformers were considered. A 1600A Automatic Mains Failure with synchronization to mains changeover panel is included to facilitate the plant black start capability.

4.1.11.22. PROCESS CONTROL

The complete plant equipment will be controlled and monitored by a main control PLC. A SCADA system will give the operator accessibility to the main and adjustable process elements. The packaged units, such as the pre-treatment line and the desulphurization plant will be integrated into this main control. A dedicated connection will assure the communication between plc and field instruments and machinery.

The control and monitoring system is a central part which forms the basis of all of the automated functions and motor controlling, including the plant's safety in operation and high efficiency.

The control system also takes care of the plant monitoring, sending alarms, archiving of records and creating documentation and can be accessed from any PC in remote location by authorized personnel, by internet connection.

A 17" panel mounted screen replicates in a schematic format, all the elements of the plant and provides status information and historical data of all components, process levels, positions of valves, temperatures and all essential information to operators in the control room.

A vast number of different screen display menus can be selected to provide status information and historical data for all mechanical and process aspects of the plant, including operating and rest intervals for each item of plant, aggregate operating time, process levels, process pressures, process flows, gas production, CHP status and performance. Each individual function of the process can be isolated, operated manually, or switched to fully automatic mode.

The monitoring, operation and control functions and services are supported in the main PLC panel, the MCC (motor control centre) panel and interfaces to the intake control station panel and CHP unit panel. The plant control valves are operated from 110 VAc. Interposing relays are used for interface to the valves. The PLC panel is equipped with battery backed supply to safely shut down the controller in the event of power failure.

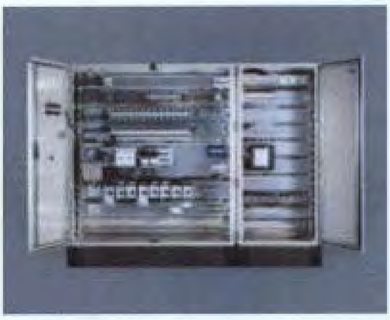


Figure 55: Control system

4.1.11.23. Centrifuge

The digestate is pumped from the secondary digester to a centrifuge which dewaters the sludge. The centrifuge can handle a throughput of max. 35 m^3/h. It is positioned on a mezzanine so the cake solids can fall by gravity into a storage area from where it can be collected and disposed of as desired. The filtrate resulting from the dewatering operation is collected in a small buffer tank made of concrete and pumped afterwards to the liquid digestate storage; some is recycled for use as process water and the rest can be reused or disposed.

Figure 56: Centrifuge

4.1.11.24. Buffer for liquid phase filtrate

The liquid phase after separation will be stored in a mixed buffer tank. The buffer tank is built of concrete. The substrate will be mixed with a powerful electrical mixer to mix the buffer tank content thoroughly. For discharge and complete emptying an external pump will be installed.

Figure 57: Buffer tank

4.2. Environmental and legal data

As part of the assessment for the proposed biogas facility at AF, Chand Environmental Consultants visited the site on 5 November 2014. The site visit was conducted with a view to investigate the environmental context of the proposed location of the facility on the Foundry property and to get a sense of potential environmental sensitivities on the site and within the surrounding area.

The site walkabout revealed two possible locations for the siting of the biogas facility, with the one located within the Business Park area being clearly preferred from a logistical perspective. From an environmental perspective, both sites are equally suited for development, given that no environmental sensitivities were observed in either of these locations. Both areas are covered with remnants of corn fields, presumably from historical farming activities in the area. A low level of alien invasive species (such as Port Jackson and Patterson's Curse) were also present on both sites, noting however that evidence of regular alien clearing was observed to prevent the spreading of these invasive species. Land use beyond the property boundaries include industrial development as well as vacant land with significant levels of alien invasion and no aquatic or terrestrial sensitivities were noted during the visit. The mapping for the area contained in the Biodiversity GIS (Geographic Information System) system will be reviewed to further understand the environment context of the greater area (Chand Environmental consultants, 2015).

The availability of two large portions of vacant land, neighbouring the foundry, presents a great opportunity for land utilization for the envisaged waste to energy project. The fairly flat terrain and easy access for the current marked land portion is a great advantage. Over and above, the EIA process requires putting forward an alternative site for the project, therefore the availability of the two land portions is a great advantage in this regard (Chand Environmental consultants, 2015).

Atlantis was recently classified as a SEZ – Special economic Zone, meaning the government will provide significant tax incentives and EIA process will be fast-tracked, making the pursuit of a waste to energy project even more lucrative. This will be further reviewed to better understand the techno-economic benefits of the SEZ to the AF project (Chand Environmental consultants, 2015).

The figure below is a summary of all the legislative requirements for a biogas project in RSA, as presented in the national biogas conference 2015 (Van Zyle, M., 2015).

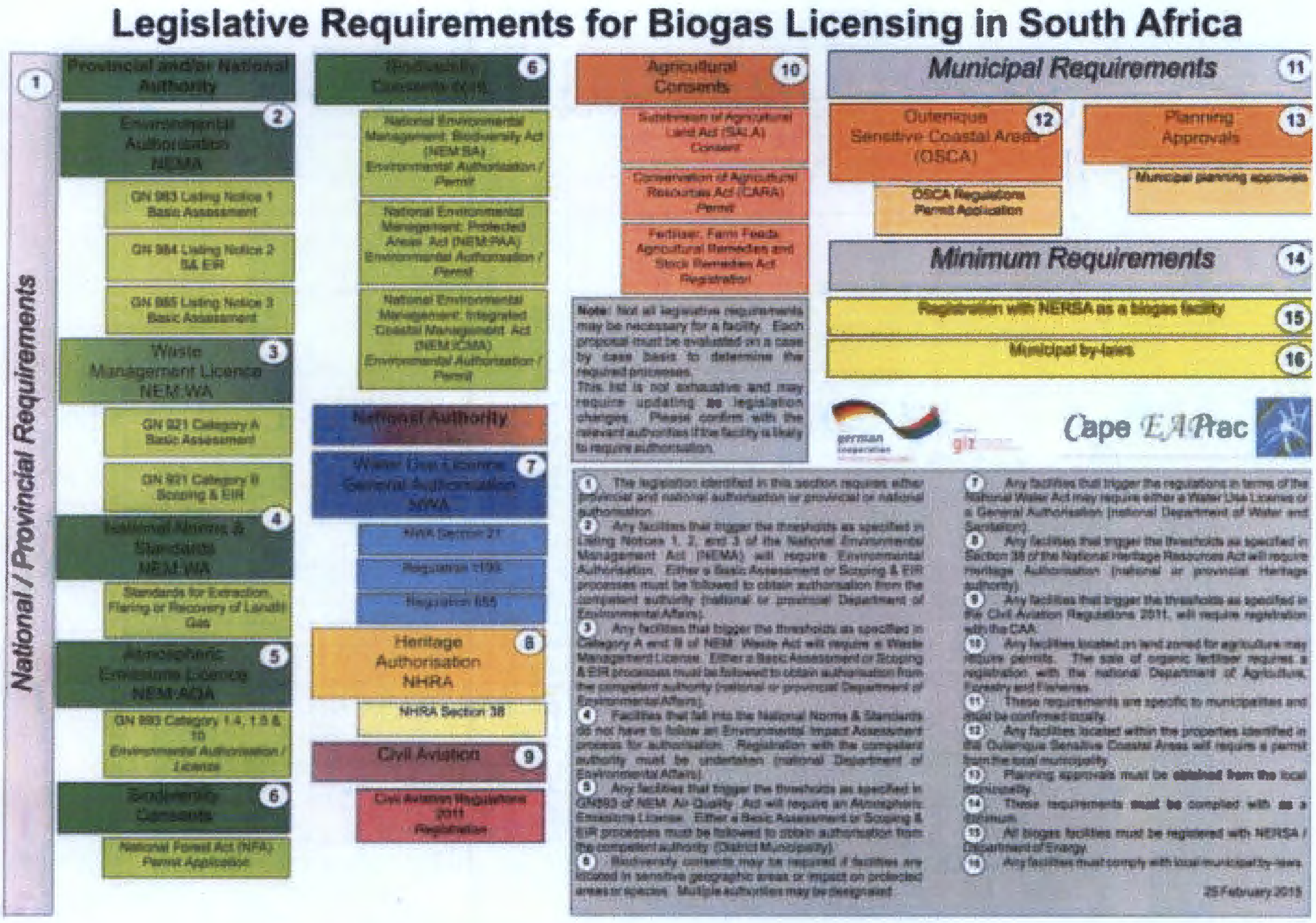
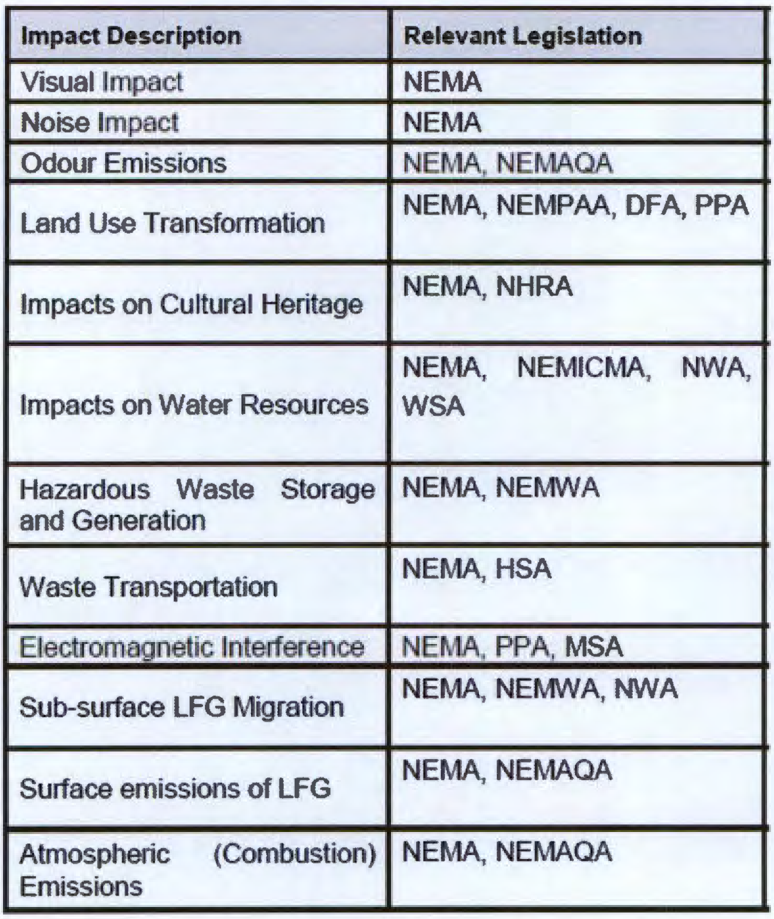


Figure 58: Legislative requirements for a biogas project in RSA

(adopted from Van Zyle, M., 2015).

The potential environmental impacts of a biogas project and their relevant legislation are described in table 27:



Impact Description	Relevant Legislation
Visual Impact	NEMA
Noise Impact	NEMA
Odour Emissions	NEMA, NEMAQA
Land Use Transformation	NEMA, NEMPAA, DFA, PPA
Impacts on Cultural Heritage	NEMA, NHRA
Impacts on Water Resources	NEMA, NEMICMA, NWA, WSA
Hazardous Waste Storage and Generation	NEMA, NEMWA
Waste Transportation	NEMA, HSA
Electromagnetic Interference	NEMA, PPA, MSA
Sub-surface LFG Migration	NEMA, NEMWA, NWA
Surface emissions of LFG	NEMA, NEMAQA
Atmospheric (Combustion) Emissions	NEMA, NEMAQA

Table 26: potential environmental impacts of a biogas project and their relevant legislation

(adopted from: DEA, 2013)

Other legislation relating to environmental matters are (Van Zyle, 2015; DEA, 2013):

- National Water Act (No 36 of 1998).
- Water Use License / General Authorization.
- The National Heritage Resources Act No. 25 of 1999 contains listed activities that trigger the need for a Heritage Impact Assessment (HIA) /Archaeology Impact Assessment (AIA).
    - WULA / HIAs / AIAs often form part of an EIA process.
    - However WULA / HIAs / AIAs can also be required when an EIA is not.
- NEMA: BA.
- Civil Aviation (2013 regulation), registering of activity.
- Bylaws (permit requirements).

4.3. GHG emission reduction data

Table 28 below summarizes the input data and assumptions used for calculating the GHG emission reduction of the chosen waste to energy scenario – 5MW P&S (see scenario choice is made in the results chapter).

Parameter	Value	Source
Emission reduction from OFMSW avoidance from landfilling		
MSW processed	132,000 ton/year	Calculated
OFMSW	65%	(Pienaar, 2014; Anaergia 2014)
DOCi of OFMSW	0.15	(IPCC, 2006)
Biogas methane fraction	48.6%	(IPCC, 2006)
Oxidation factor	0.1	(IPCC, 2006; CoCT, 2011)
Methane global worming factor	21	(Clemens et al., 2006).
Emission reduction from fuel switch		
Renewable electricity sold to AF	28,200,000 kWh/year	Calculated
Renewable heat used	13,440,000 kWh/year	Calculated
Eskom's electricity generation carbon dioxide emission factor	1.015 kg CO_2 per kWh	(Letete et al., 2009)
LPG carbon dioxide emission factor	0.06 kg CO_2 per kWh	(IPCC, 2007)
Emissions from biogas activity		
Biogas production	38,400 m^3/day	Calculated
Renewable electricity generated	31,360,000 kWh/year	Calculated
The leakage factor	5%	(IPCC, 2006)
Emissions from combustion of biogas in a CHP unit	0.9 Kg carbon dioxide per kWh of electricity generated	(Cuéllar, 2008)

Table 27: GHG emission reduction data

5. Results and Discussions

This chapter presents the results of this study. The information in this chapter is arranged under the following main subsections: technical results, economic feasibility results, environmental results and GHG emission reduction results.

5.1. Technical results

This subsection covers results relating to the practical implementation of the project, like location selection, traffic impact assessment results, etc. such results were used in order to finalize the design of the waste to energy project scenarios, which are also presented as technical results in this subsection, these are provided in the form of process design philosophy, mass and energy balance, layouts, etc. These results are then further used to come up with the financial, environmental and GHG emission reduction results, which are presented later.

5.1.1. The site

Out of the two options identified in the previous stages, the marked vacant land in Figure 59 below was identified as the most feasible option for any of the project scenarios investigated. That is mainly due to:

- Topography: the land is more flat and according to Anaergia's engineers assessment is more stable for civil construction than the alternative.
- Access: the land is more accessible in terms of existing infrastructure (road access).
- Electricity off-take: the land is closer to the main foundry transformer, which is identified as the most feasible point of connection.

Figure 59: Atlantis Foundries project site
(Google Earth, 2014)

5.1.2. Traffic and access

In terms of access from the public roads, Atlantis Foundries location in a major industrial zone, between the R27 to the West and the R304 to the East, makes it very feasible to access by waste trucks.

In terms of traffic, the different project scenarios will require different traffic flows, as presented in table 29 below. Anaergia engineers calculated the densities of the digestate and compost out to be 350 and 700 kg/m^3 respectively, the density of the waste coming in is estimated by Waste Man to be 250 kg/m^3. For the purpose of this calculation a truck with 30 m^3 capacity was used.

Scenario	Waste in [t/y]	m^3/y	Waste out [t/y]	m^3/y	Compost out [t/y]	m^3/y	Trucks in [y]	Trucks out [y]	Trucks in [d]	Trucks out [d]
2MW continuous	88,000	352,000	35,200	100,571	13,900	19,857	11,733	4,014	33.5	11.5
3MW continuous	125,000	500,000	51,200	146,286	18,000	25,714	16,667	5,733	47.6	16.4
5MW continuous	210,000	840,000	84,000	240,000	33,100	47,285	28,000	9,576	80	27.4
5MW peak & standard	132,000	528,000	54,100	154,571	19,100	27,286	17,600	6,062	50.3	17.3
5MW peak	44,100	176,400	17,600	50,286	4,200	6,000	5,880	1,876	16.8	5.4
10MW peak	88,000	352,000	35,200	100,571	13,900	19,857	11,733	4,014	33.5	11.5

Table 28: Atlantis Foundries waste to energy scenarios traffic impact

Considering the current average daily truck flow to Atlantis of 72 trucks, the waste to energy project trucks flow impact will vary between 70% and 23% depending on scenario. This impact range was found acceptable and manageable by AF and there for making the traffic impact of the project feasible. A separate entrance to the AF site can assist in avoiding or minimizing the waste to energy project traffic impact on AF existing operations.

The following entrance points to Atlantis Foundries in terms of the waste to energy project were identified as available and marked in the Figure 60 below.

Figure 60: Atlantis Foundries industrial park entrance points

(Google Earth, 2014)

Table 30 below summarizes the entrance points current purposes, typical daily trucks traffic flow and pros (+) and cons (-) in terms of the feasibility for the waste to energy project.

Gate	Purpose	Typical daily truck flow	Feasibility
1: main foundry gate	Main entrance to the foundry	0	+ close to the W2E site - has to pass through 5 - not catered for trucks
2: North gate	Weigh bridge gate	35	+ existence of weigh bridge + catered for trucks - far from the W2E site - has to pass through 5
3: North gate	Main entrance to the business park	9	+ avoid passing through 5 - far from the W2E site - disturbance to residence

4: South gate	South entrance to the site	28	+ avoid passing through 5 + catered for trucks - far from the W2E site - disturbance to residence
5: inner gate	Separating the foundry and the business park		
6: new gate from parking area	New potential gate from the parking area	0	+ close to the W2E site + avoid passing through 5 + minimal disturbance to existing operations - needs to be built

Table 29: Evaluation of Atlantis Foundries waste to energy entrance point

Based on the above evaluation and AF opinion, option 6 was identified as the most feasible option followed by 2.

For option 6, the project team consulted with Cape Town's environmental authorities and got positive feedback on the possibility for a new access point. However this matter is still to be finalised with the authorities.

5.1.3. Electrical interconnection siting

From the findings of the site audit, interviews with Atlantis personal as well as considering the existing electrical infrastructure in place, the ideal point of connection for supply of the renewable electricity from the waste to energy project was chosen to be the main foundry substation, as marked in Figure 61.

Figure 61: Atlantis Foundries waste to energy project interconnection with existing electricity supply substation

(Google Earth, 2014)

This interconnection, with the existing electrical infrastructure allows AF to utilize the renewable electricity anywhere in the foundry, and to limit it to its critical equipment (i.e. equipment that runs 24/7, even during load shedding e.g. the holding furnaces, critical cooling pumps that cools the melting and holding furnaces and the foundry emergency lights).

5.1.4. Heat and sand drying

The amount of heat required to substitute the current thermal load of sand drying is calculated as follows:

1.6 [MW] * 24 [hours/day] * 350 [days/year] = 13,440,000 kWh (thermal)/year

AF has a relatively high LPG consumption (to other industries in the Western Cape) and it pays a fairly high price for it. However its LPG consumption is much lower compare to its electricity consumption in energy terms making it less relevant for replacement by biogas. Over and above, the large physical spread of the LPG consumers over the foundry site and the lack of burners at some of the LPG consumers, implies that the replacement of LPG with biogas won't be feasible due to the relatively high capital costs required for long distance piping. For the two reasons above LPG replacement with biogas was not included in the financial evaluation of this study.

The amount of heat required for maintaining the digester at mesophilic temperature, for each scenario is presented in table 31 below.

Scenario	Heat power demand (KW)	Heat energy demand (MWh/year)
2MW c	240	1,000
3MW c	350	1,500
5MW c	630	2,980
5MW P&S	350	1,480
5MW p	120	480
10MW p	240	1,020

Table 30: thermal energy self-consumption

For reference, the 5MW peak and standard project CHP unit generates 31 million kWh per year of total thermal energy out of which 13.44 million kWh of thermal energy are sold to AF for sand drying.

5.1.5. Diesel

AF has a fairly low diesel consumption compared to its electricity consumption in energy terms. Its main use as a forklift fuel marks the replacement of diesel with biogas at a lower priority to electricity.

5.1.6. On site solid waste

Atlantis has 2,300 tons per year of suitable solid waste (general waste), which is only 1.7% of the required 132,000 tons per year for the selected waste to energy project scenario and therefore won't be considered in the feasibility evaluation.

5.1.7. Water and Sewerage

During the scoping phase, the average fresh water usage and sewerage discharge were identified: 6,121 and 5,815 m^3 per year respectively.

The waste to energy project will produce liquid effluent which varies between 48,700 and 119,400 m^3 per year and will consume between 20,200 and 65,400 m^3 per year of fresh water. The fresh water to the AD will be supplied from the same AF municipal supply point and the sewerage will be discharged to the existing sewerage infrastructure. The municipal sewerage discharge limits were considered in the design, to accommodate discharge to the municipal sewerage system.

These are significant amounts in comparison with the existing ones, however the environmental specialist with the advice of Cape Town municipality environmental affairs office, concluded that the fresh water and sewerage existing infrastructures in Atlantis will be able to handle these amounts (Chand Environmental consultants, 2015).

The relatively low sewerage amounts does not present an opportunity for treating AF sewerage in the waste to energy plant and allowing a meaningful cost reduction on its sewerage bill. Therefore this option was not considered in the plant design and in the feasibility model.

5.1.8. Cooling water

AF has a reasonable requirement for cooling water, which may present an opportunity for treating and utilizing waste water from the waste to energy plant, to allow some cost savings on fresh water and\or effluent disposal. However due to the use of anti-fouling chemicals in the cooling water this option won't be considered.

5.1.9. Process design and philosophy

The process design and philosophy of the chosen scenario as well as all other scenarios are presented in section 4.1.11. of the data chapter.

5.1.10. Lay out

All the scenarios layouts are presented in appendix 3. The chosen project scenario layout is given in the figure below.

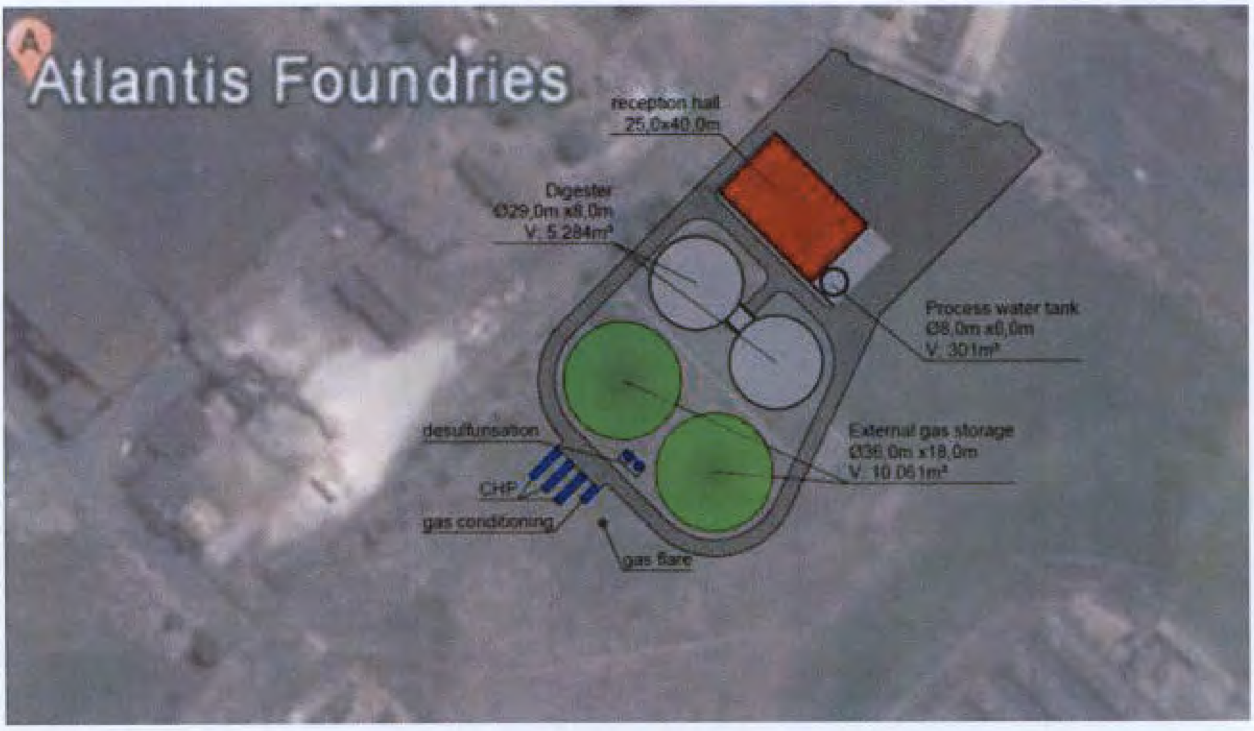


Figure 62: 5MW peak and standard scenario layout
(adopted from Anaergia, 2015)

In the figure, in clock direction: Reception hall 25x40m; Process waster tank D8m, H6m, V30m^3; External gas storage D36m, H18m, V10.06m^3; Gas flare; Gas conditioning; CHP; desulfurisation; Digester D29m, H8m, V5,284m^3;

5.1.11. model main inputs and outputs summary

All the scenarios main inputs and outputs summaries are presented in appendix 7. The chosen project scenario main inputs and outputs summaries is given in table 32 below.

Project name	Atlantis foundries 5MW peak & standard			
Substrate	SSO (Source Separated Organic)			
Organic fraction	60.0%			
Substrate flow	377.14	ton/day	132,000	ton/year
Biogas production	38,400	m3/day	1,600	m3/h
Electricity generation mode	Peak and standard			
Electricity generation hours	16	hour/day		
Energy production (after parasitic load)	28,200,000	kWh/year		
Power over continues operation	5.60	MW		
Power over specific operation	5.04	MW		
Heat available	31,000,000	kWh/year		
Heat sold\used	13,440,000	kWh/year		
Liquid effluent production	72,900	m^3/year		
Solid effluent production - Compost	20,800	ton/year		
Waste rejects for dumping/recycling	52,800	ton/year		
Polymers	47	ton/year		
Gate fee	318.00	Rand/ton		
Electricity selling\buying price	0.91	Rand/kWh		
Heat selling price	0.34	Rand/kWh		
Recyclables/rejects dumping cost (+transportation to vissershok)	-540.6	Rand/ton		
Compost \ organic fertilizer selling price	0.00	Rand/ton		

Water price	12.11	Rand/m^3		
Liquid effluent sewage discharge price	9.31	Rand/m^3		
Polymers weighted average price	28,100	Rand/ton		
Salaries	1,920,000	Rand		
O&M services	1,769,398	Rand		
Insurance	884,699	Rand		
Maintenance	5,308,195	Rand		
Land Lease	-	Rand		
Admin fees	72,000	Rand		
Capex	176,939,820	Rand		
Sales (year1)	72,117,888	Rand		
Variable Costs (year1)	33,203,214	Rand		
Fixed costs & overheads (year1)	9,954,292	Rand		
EBITDA (year1)	28,960,382	Rand		
Simple payback	5.2	Years		
IRR 10	17%			
IRR 20	23%			
NPV interest	8%	CPI	6%	
NPV 10	80,207,659	Rand		
NPV 20	315,845,788	Rand		

Table 31: 5MW peak and standard scenario model main inputs and outputs summary

5.1.12. Process flow diagram (PFD)

All the scenarios PFDs are presented in appendix 4. The chosen project scenario PFD is given in the figure below.

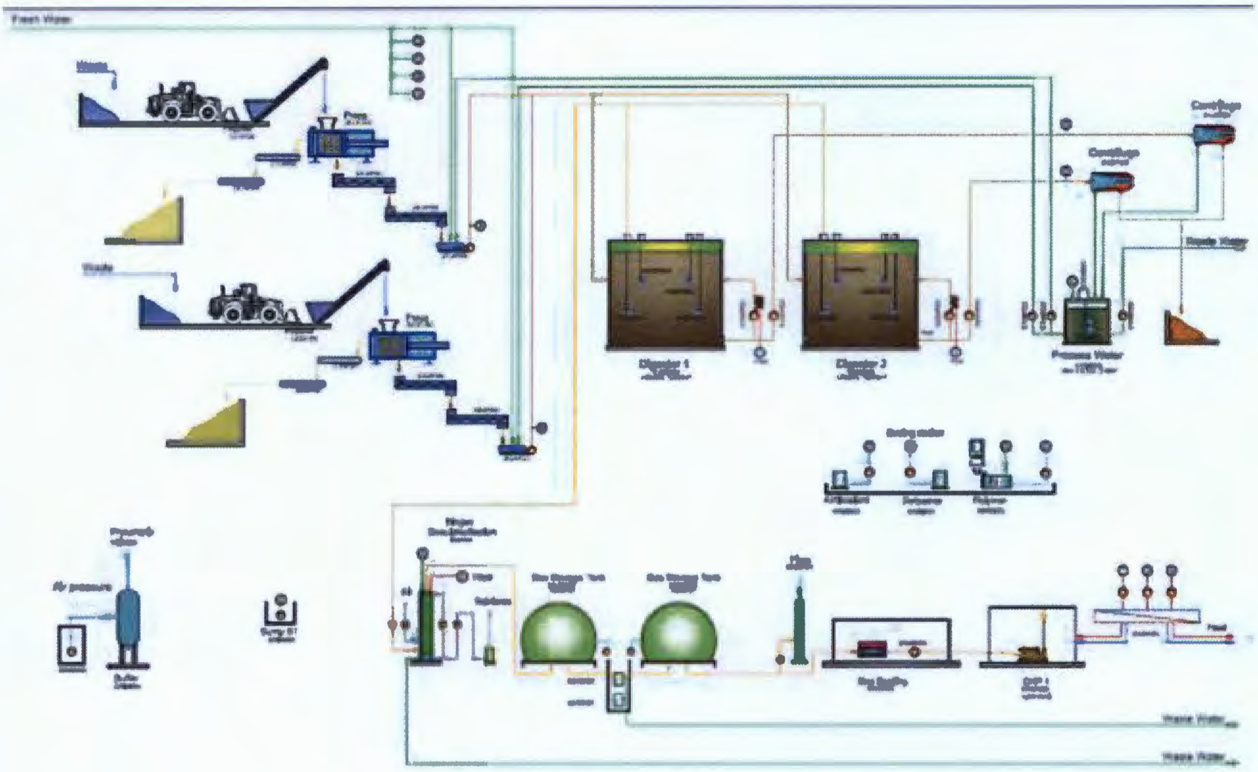
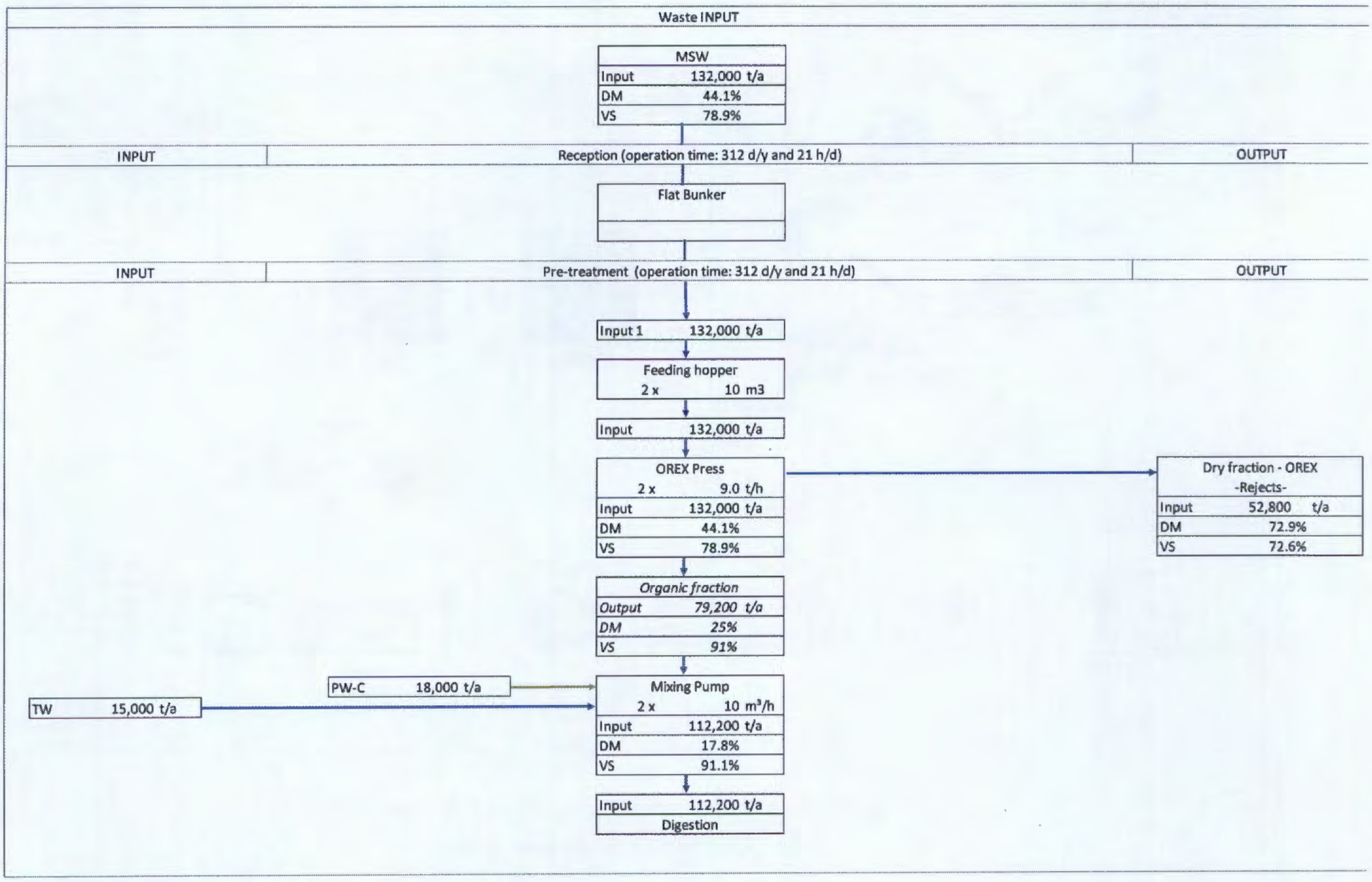


Figure 63: 5MW peak and standard scenario PFD
(adopted from Anaergia, 2015)

5.1.13. Mass and energy balance

All the scenarios mass and energy balances are presented in appendix 5. The chosen project scenario mass and energy balances is given in the figure below.



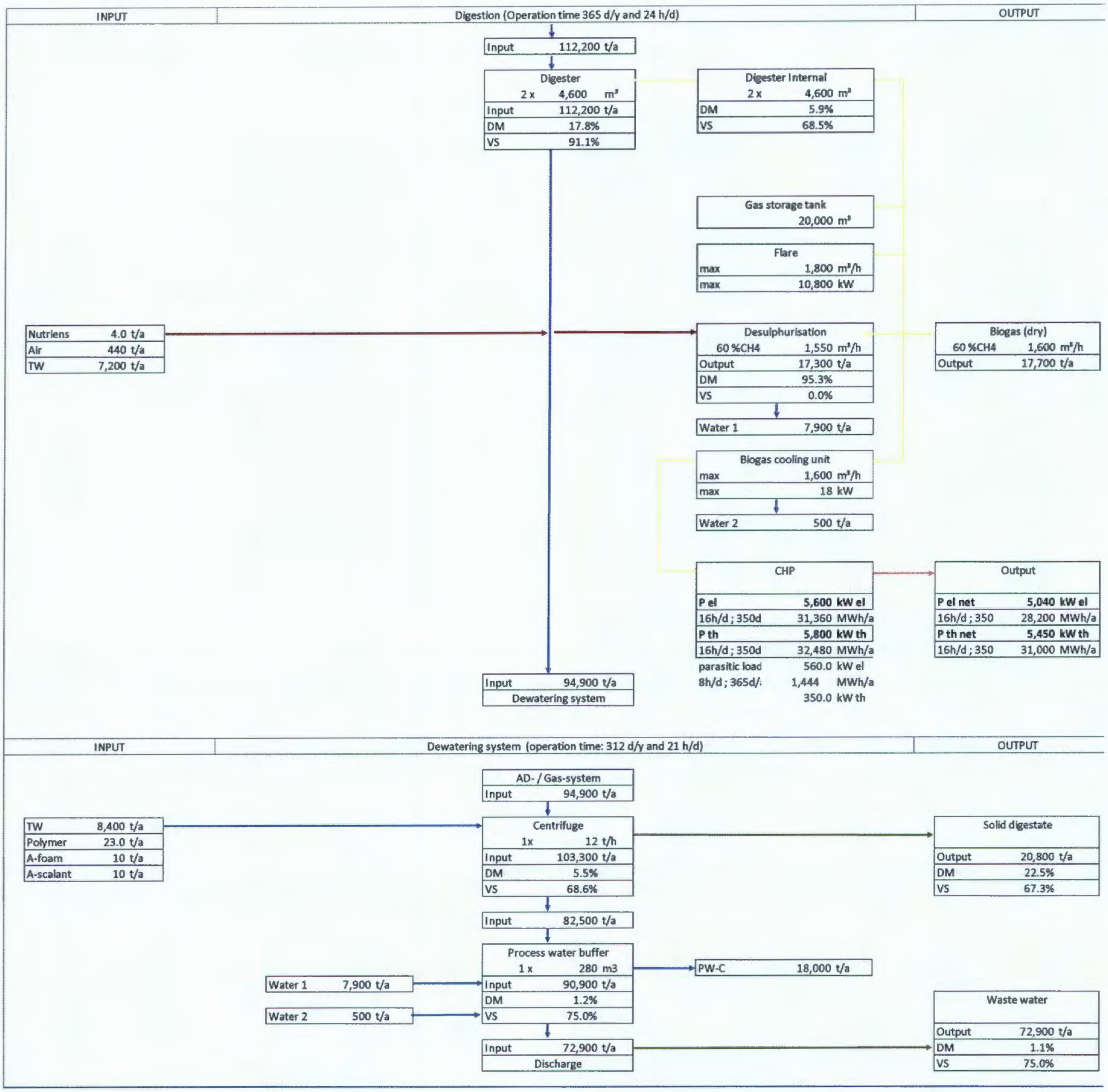


Figure 64: 5MW peak and standard scenario mass and energy balance (adopted from Anaergia, 2015)

5.1.14. Main technical parameters and total capex

Table 33 below present the main design parameters of the different project scenario key capital components.

Component \ Scenario	Waste (t/y)	Digesters size (m^3) and number	Biogas production (m^3/h)	Gas storage (m^3)	CHP size (MW) and number	Electric energy produced (kWh/y)	Capex (R)
2MW	88,000	2 x 3,200	1,000	1,050	1 x 2.5MW	16,500,000	121,847,523
3MW	125,000	2 x 4,600	1,500	1,500	2 x 1.8MW	25,100,000	164,050,238
5MW (C)	210,000	4 x 4,600	2,500	2,500	2 x 2.5MW	42,400,000	252,614,081
5MW (P&S)	132,000	2 x 4,600	1,600	20,000	2 x 2.5MW	28,200,000	176,939,820
5MW (P)	44,000	1 x 3,200	500	10,000	2 x 2.5MW	8,800,000	123,238,224
10MW (P)	88,000	2 x 3,200	1,000	20,000	4 x 2.5MW	17,600,000	208,804,715

Table 32: Atlantis Foundries waste to energy project scenarios main design parameters

5.1.15. Main Capex components

The different AF MSW AD to energy project scenario components choice and design were done with the advice and guidance of Anaergia (Anaergia, 2014). Special consideration was given to operation and cost optimization. All the different scenarios share the same main components only with different size and capacity design, table 33 below presents the project scenarios main components and their respective percentages of the overall cost. For confidentiality reasons the costs of each component is not presented in this study but only the overall different project scenario capital costs.

Item \ Scenario	2MW C	3MW C	5MW C	5MW P	5MW P&S	10MW P
Project general planning and preparation						
Legal permissions (building, environmental, etc.)	0.8%	0.6%	0.6%	0.7%	0.5%	0.4%
Basic engineering design	1.0%	0.8%	0.8%	0.9%	0.7%	0.6%
Detailed engineering design	2.5%	1.9%	1.8%	1.9%	1.6%	1.3%
Health and Safety, documentation, others	1.0%	0.8%	0.8%	0.9%	0.7%	0.6%
Plant construction						
Earthworks complete	2.6%	2.1%	1.9%	2.1%	1.7%	1.3%
Reception hall incl. Tipping floor, rooms and others)	5.9%	4.6%	4.4%	4.4%	3.8%	3.2%
Streets and other civils	2.4%	1.9%	1.8%	1.8%	1.5%	1.3%
concrete works (basement, foundations, walls)	0.6%	0.5%	0.5%	0.5%	0.4%	0.5%
Pretreatment line (hopper, press, screw, pump)	15.8%	15.7%	14.8%	14.4%	20.5%	10.7%
tank construction	7.4%	7.9%	7.4%	3.6%	6.3%	3.9%
mixing technology incl. Equipment	2.9%	3.2%	3.0%	1.9%	3.4%	2.2%

Pumps and other technology	1.5%	1.2%	1.1%	0.8%	0.9%	0.8%
heating technology and water installation	2.2%	2.0%	1.9%	1.2%	1.6%	1.3%
gas storage (2 x 10.000 m³)	0.8%	0.9%	1.0%	2.4%	3.1%	2.6%
pipe construction	3.9%	3.1%	2.9%	2.2%	2.5%	2.1%
C&I technology (Electrical and control)	5.0%	5.3%	5.3%	5.3%	5.3%	5.3%
Steel construction (platforms and ladders)	0.8%	0.6%	0.6%	0.5%	0.5%	0.4%
technology building and Container	0.9%	0.7%	0.7%	0.8%	0.6%	0.5%
Other technology (pressed Air system, etc.)	0.4%	0.3%	0.3%	0.3%	0.2%	0.2%
Separation technology (centrifuge, dosing, etc.)	3.0%	2.4%	2.3%	1.9%	3.9%	3.0%
Gas section (cooling, blower)	1.3%	1.5%	1.4%	0.6%	1.2%	2.2%
Gas conditioning (ext. Desulph., filters)	3.0%	2.8%	2.7%	2.1%	2.3%	1.7%
Gas flare	0.8%	0.7%	0.7%	0.6%	0.6%	0.5%
Gas Utilization (CHP Jenbacher) 4 x 2,5 MW	20.2%	26.8%	29.9%	36.5%	25.4%	43.2%
Peripheries (fence, door, etc.)	1.0%	0.8%	0.7%	0.7%	0.6%	0.5%
Project Management (internal & external)	3.0%	2.4%	2.2%	2.2%	1.9%	1.6%
cold commissioning	0.5%	0.4%	0.4%	0.3%	0.3%	0.3%
hot commissioning	1.5%	1.2%	1.1%	1.4%	0.9%	0.8%
Other costs						
Traveling, etc.	0.5%	0.4%	0.4%	0.5%	0.3%	0.3%
Warranty	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Insurance	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Bank	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Contingency	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

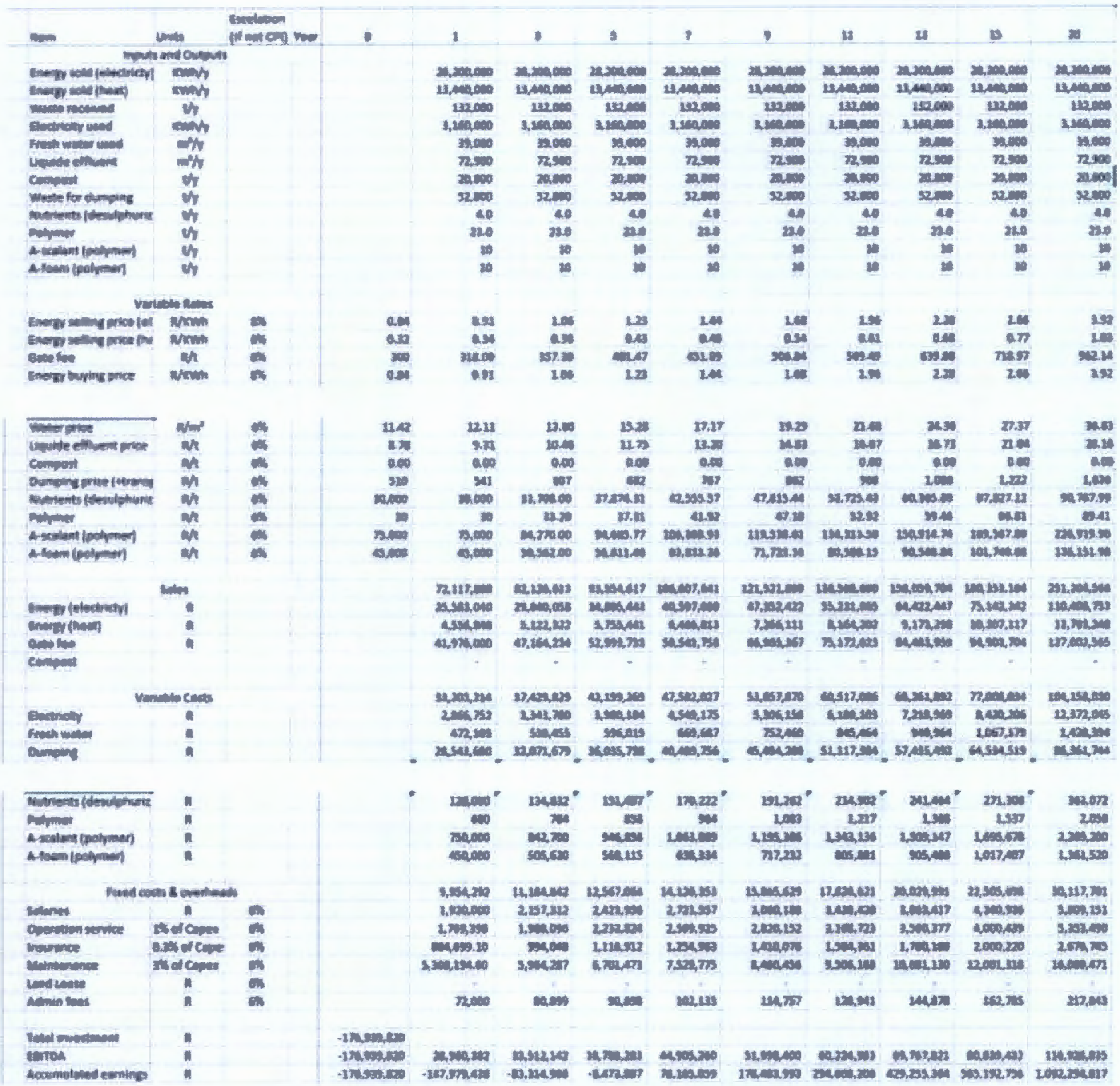
TableTable 33: Atlantis foundries waste to energy project scenarios main capital components and their percentages of the overall cost (Anaergia, 2014)

5.2. Economic feasibility results

The economic feasibility results of each scenario were extracted from the techno-economic model made for the purpose of this study. The cash flow projection and its respective financial indicators of the chosen scenario are presented in figure 65 below. The economic feasibility results of all the other scenarios are in appendix 6.

Figure 65 below, is divided into 7 categories:

- Inputs and outputs – which included the annual quantities of project main incoming and outgoing streams. This included:
  - Electric and thermal energy produced by the project and used to displace AF current energy demand.
  - Liquide effluent and compost which are the output streams from the centrifuge.
  - Waste for dumping which is the non-organic fraction of the project feedstock which needs to be dumped.
  - Nutrients required for the desulphurization biological process and polymers which are required for the AD biological process and the solid liquid separation mechanical process.
- Variable rates – which are the costs in Rand of the inputs and outputs streams. The escalation rate of these costs are presented in the escalation column.
- Sales – which is the financial income streams of the project. These are the results of the multiplication of the outputs quantities by their respective rates.
- Variable costs – which are the project costs that are a function of the project throughput. These are the results of the multiplication of the project consumables quantities by their respective rates.
- Fixed costs and overheads – which are the project costs that are not a function of the project throughput. These costs were determined previously in this study or calculated as a percentage of Capex.
- A cash flow summary – which included the total project capex, EBITDA (Earnings Before Income, Tax, Depreciation and Amortization) and accumulated earnings (accumulated EBITDA) in Rands.



Item	Units	Escalation (if not CPI)	Year	0	1	3	5	7	9	11	13	15	20
Inputs and Outputs													
Energy sold (electricity)	kWh/y				28,200,000	28,200,000	28,200,000	28,200,000	28,200,000	28,200,000	28,200,000	28,200,000	28,200,000
Energy sold (heat)	kWh/y				13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000
Waste received	t/y				132,000	132,000	132,000	132,000	132,000	132,000	132,000	132,000	132,000
Electricity used	kWh/y				3,160,000	3,160,000	3,160,000	3,160,000	3,160,000	3,160,000	3,160,000	3,160,000	3,160,000
Fresh water used	m³/y				39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Liquide effluent	m³/y				72,900	72,900	72,900	72,900	72,900	72,900	72,900	72,900	72,900
Compost	t/y				20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Waste for dumping	t/y				52,800	52,800	52,800	52,800	52,800	52,800	52,800	52,800	52,800
Nutrients (desulphuriz	t/y				4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Polymer	t/y				23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0
A-scalant (polymer)	t/y				10	10	10	10	10	10	10	10	10
A-foam (polymer)	t/y				10	10	10	10	10	10	10	10	10
Variable Rates													
Energy selling price (el	R/kWh	8%		0.84	0.91	1.06	1.23	1.44	1.68	1.96	2.28	2.66	3.92
Energy selling price (he	R/kWh	6%		0.32	0.34	0.38	0.43	0.48	0.54	0.61	0.68	0.77	1.03
Gate fee	R/t	6%		300	318.00	357.30	401.47	451.09	506.84	569.49	639.88	718.97	962.14
Energy buying price	R/kWh	8%		0.84	0.91	1.06	1.23	1.44	1.68	1.96	2.28	2.66	3.92
Water price	R/m³	6%		11.42	12.11	13.60	15.28	17.17	19.29	21.68	24.36	27.37	36.63
Liquide effluent price	R/t	6%		8.78	9.31	10.46	11.75	13.20	14.83	16.67	18.73	21.04	28.16
Compost	R/t	6%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dumping price (+transp	R/t	6%		510	541	607	682	767	862	968	1,088	1,222	1,636
Nutrients (desulphuriz	R/t	6%		30,000	30,000	33,708.00	37,874.31	42,555.37	47,815.44	53,725.43	60,365.89	67,827.12	90,767.99
Polymer	R/t	6%		30	30	33.70	37.81	41.92	47.10	52.92	59.46	66.81	89.41
A-scalant (polymer)	R/t	6%		75,000	75,000	84,270.00	94,685.77	106,388.93	119,538.61	134,313.58	150,914.74	169,567.80	226,919.98
A-foam (polymer)	R/t	6%		45,000	45,000	50,562.00	56,811.49	63,833.36	71,723.16	80,588.15	90,548.84	101,740.68	136,151.98
Sales					72,117,888	82,126,613	93,554,617	106,607,641	121,521,900	138,568,600	158,059,704	180,353,164	251,204,566
Energy (electricity)	R				25,583,040	29,840,058	34,805,441	40,597,080	47,352,422	55,231,880	64,422,447	75,142,342	110,408,753
Energy (heat)	R				4,558,848	5,122,322	5,755,441	6,466,813	7,266,111	8,164,202	9,173,298	10,307,117	13,793,248
Gate fee	R				41,976,000	47,164,234	52,993,733	59,543,758	66,903,367	75,172,025	84,463,958	94,903,704	127,002,565
Compost					-	-	-	-	-	-	-	-	-
Variable Costs					33,203,214	37,429,829	43,199,369	47,582,027	53,657,870	60,517,086	68,261,892	77,008,034	104,158,030
Electricity	R				2,866,752	3,343,780	3,900,104	4,548,175	5,306,150	6,188,103	7,218,969	8,420,206	12,372,065
Fresh water	R				472,108	530,455	596,015	669,687	752,460	845,464	949,964	1,067,379	1,428,394
Dumping	R				28,543,680	32,071,679	36,035,788	40,489,756	45,494,288	51,117,384	57,435,492	64,534,519	86,361,744
Nutrients (desulphuriz	R				120,000	134,832	151,497	170,222	191,262	214,902	241,464	271,308	363,072
Polymer	R				680	764	858	964	1,083	1,217	1,368	1,537	2,056
A-scalant (polymer)	R				750,000	842,700	946,858	1,063,889	1,195,386	1,343,136	1,509,147	1,695,678	2,269,200
A-foam (polymer)	R				450,000	505,620	568,115	638,334	717,232	805,881	905,488	1,017,407	1,361,520
Fixed costs & overheads					9,954,292	11,184,842	12,567,064	14,120,353	15,866,629	17,826,621	20,029,591	22,505,498	30,117,701
Salaries	R	6%			1,920,000	2,157,312	2,423,906	2,723,557	3,060,180	3,438,420	3,863,437	4,340,986	5,809,151
Operation service	1% of Capex	6%			1,769,398	1,988,090	2,233,824	2,509,925	2,820,152	3,168,723	3,560,377	4,000,439	5,353,490
Insurance	0.5% of Capex	6%			884,699.10	994,048	1,116,912	1,254,963	1,410,076	1,584,361	1,780,188	2,000,220	2,676,745
Maintenance	3% of Capex	6%			5,308,194.80	5,964,287	6,701,473	7,529,775	8,460,456	9,506,168	10,681,130	12,001,318	16,060,471
Land Lease	R	6%			-	-	-	-	-	-	-	-	-
Admin fees	R	6%			72,000	80,899	90,898	102,133	114,757	128,941	144,878	162,785	217,843
Total investment	R			-176,939,820									
EBITDA	R			-176,939,820	28,960,382	33,512,142	38,788,283	44,905,260	51,998,400	60,224,903	69,767,821	80,839,433	116,928,835
Accumulated earnings	R			-176,939,820	-147,979,438	-83,314,908	-8,473,807	78,180,039	176,483,593	294,008,200	429,255,364	583,392,756	1,092,294,817

Figure 65: Economic feasibility results, 5MW peak and standard scenario

Table 34 below is a summary of several key parameters in the waste to energy project, for all six scenarios. Based on the financial indicators (mainly IRR20), the last column "rank" was concluded.

Scenario	Waste [t/y]	Energy (e) [kWh/y]	Capex [R]	Pay back [y]	IRR20	NPV20	Rank	NPV/Waste	Rank2
2MW (c)	88,000	16,500,000	121,847,523	7.4	16%	99,212,451	4	1,127	5
3MW (c)	125,000	25,100,000	164,050,238	6.4	18%	192,249,015	3	1,538	4
5MW (c)	210,000	42,400,000	252,614,081	5.7	21%	372,685,174	2	1,775	3
5MW (p&s)	132,000	28,200,000	176,939,820	5.2	23%	315,845,788	1	2,393	1
5MW (p)	44,000	8,800,000	123,238,224	9.6	11%	42,053,511	6	956	6
10MW (p)	88,000	17,600,000	208,804,715	7.6	15%	168,802,433	5	1,918	2

Table 34: summary of key parameters of the Atlantis Foundries waste to energy scenarios modelling

It can be witnessed that:

a. Peak generation scenarios have a higher capex to output ratio, are less favorable in terms of financial indicators, this is mainly due to the much lower amount of electrical energy they produce in comparison to the other scenarios. Their Capex requirements is also high in comparison to the other scenarios and especially when taking into account their lower energy generation. Their advantage however is the low amount of waste they require and the respective rejected waste they produce.
b. Considering the possibility that financial drivers will change over time and so more eco-efficient project may be rewarded more strongly in future green-economy, NPV to waste ratio is calculated and ranked. The NPV to waste ratio indicates how profitable is the project per weight of waste processed, the higher the ratio the more eco-efficient the project is. It can be witnessed that the 5MW peak and standard and the 5MW peak remains the most faverabol and unfavorable projects respectively, though there some changes in the other rankings.
c. The 5MW peak and standard generation scenario is the most attractive one in terms of financial indicators. It shows that avoiding off-peak generation, can improve the project business case significantly. This is expected due to the significantly lower off-peak electricity price. On the other hand the peak and standard generation scenario is more attractive than the peak generation scenario, this can be explained by the relative large amount of standard hours and the reasonable cost of standard time electricity, compared with the additional capex required to increase the project size from peak to peak and standard.

5.3. Sensitivity analysis

The sensitivity analysis results for all scenario are presented below in figures 67 to 72. All scenarios sensitivity analysis can also be found, in more details, in appendix 8.

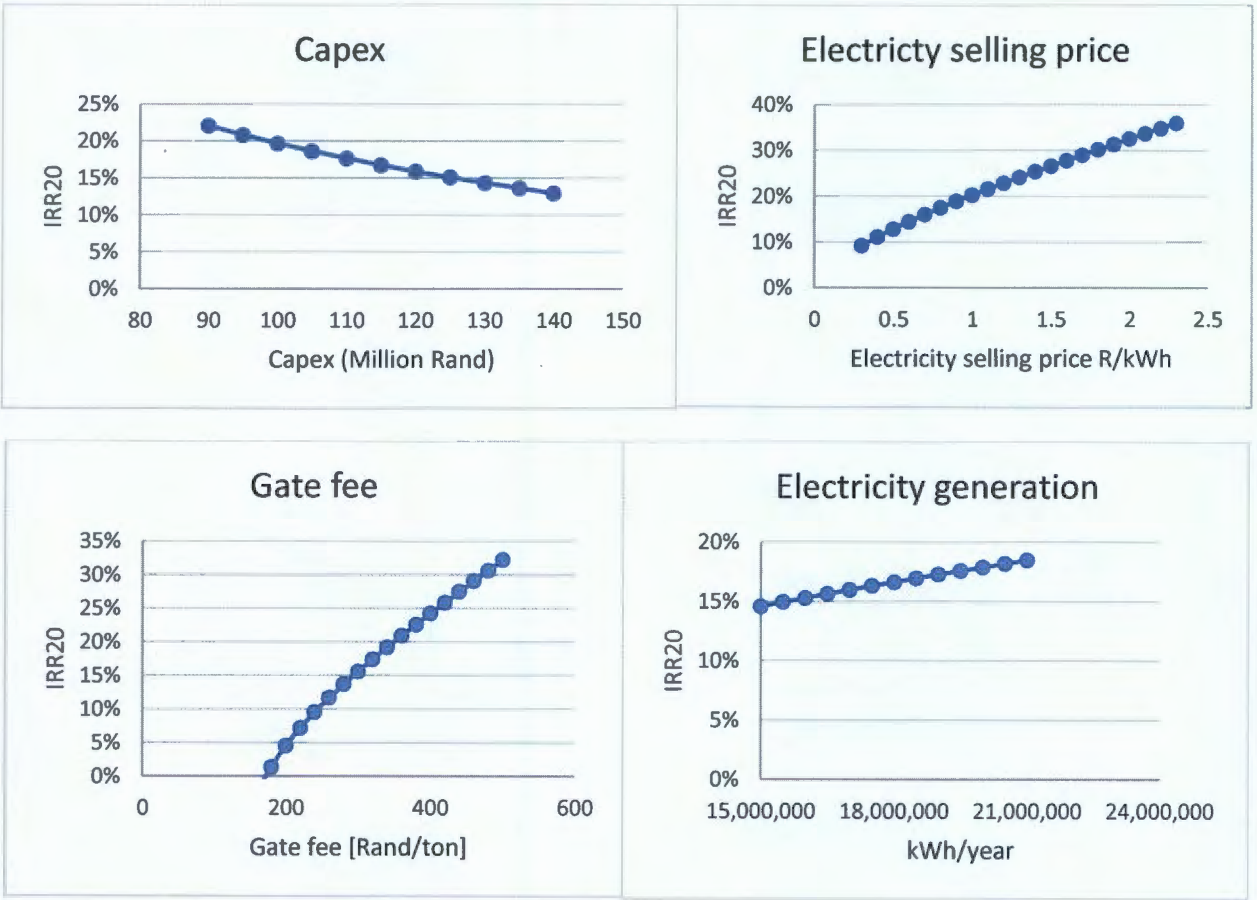


Figure 66: 2MW continuous scenario, sensitivity analysis

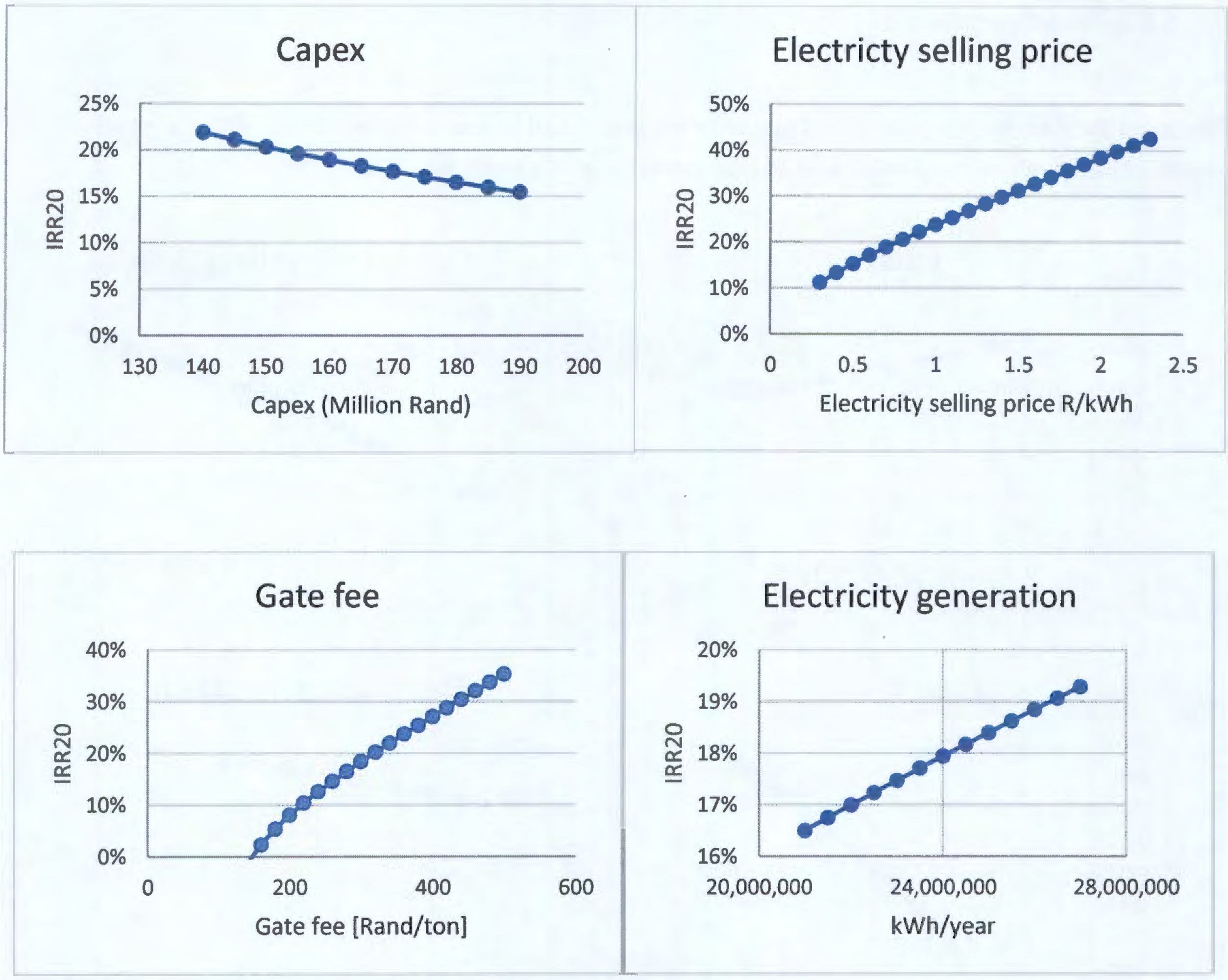


Figure 67: 3MW continuous scenario sensitivity analysis

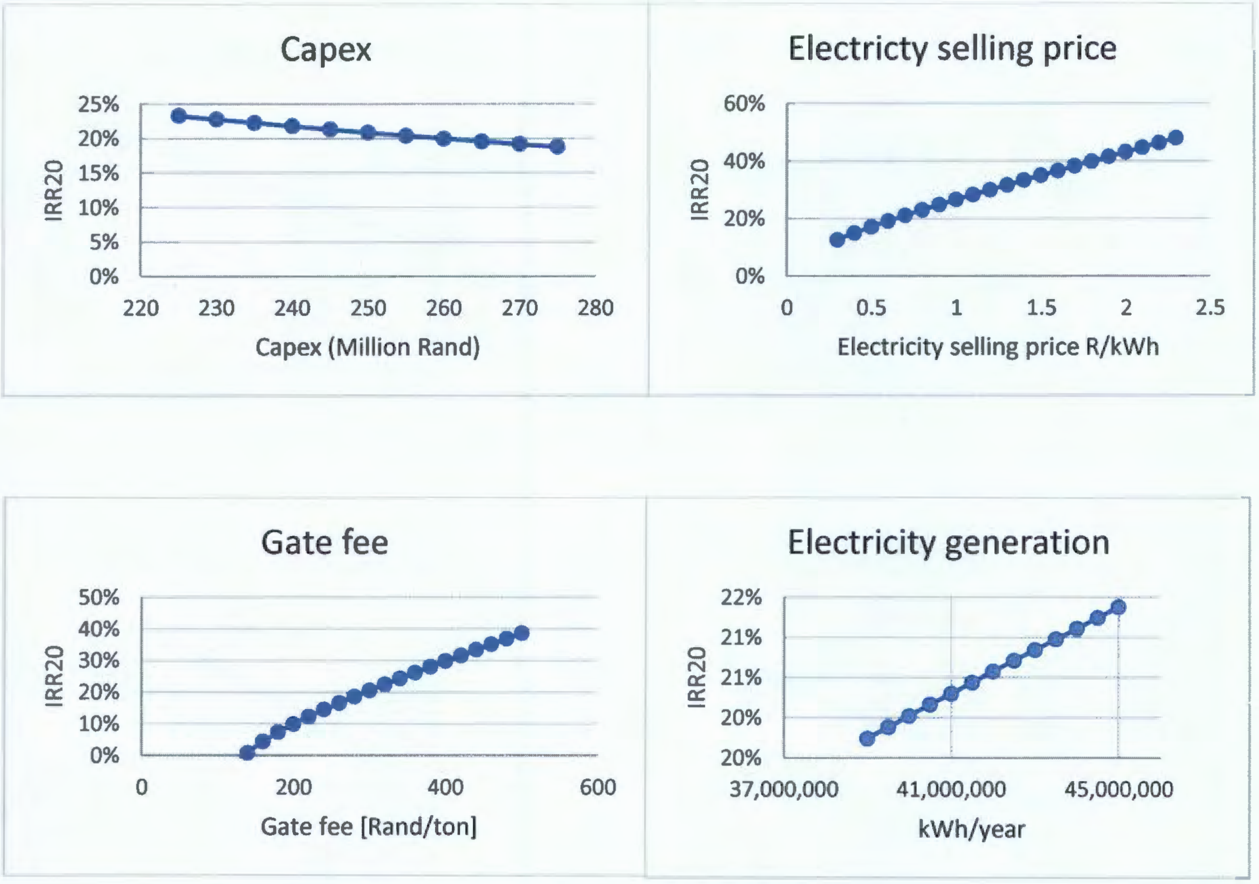


Figure 68: 5MW continuous scenario sensitivity analysis

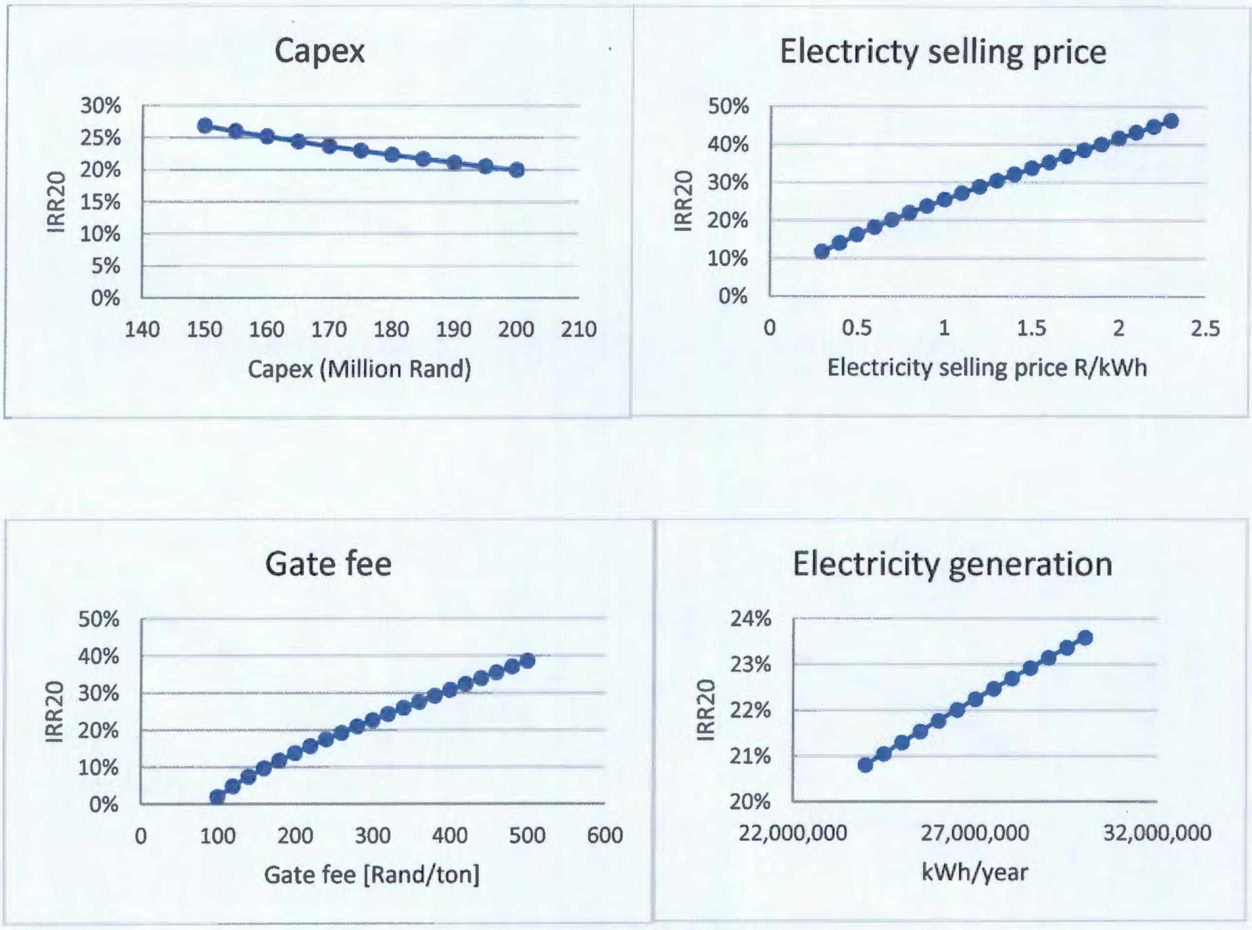


Figure 69: 5MW peak and standard scenario sensitivity analysis

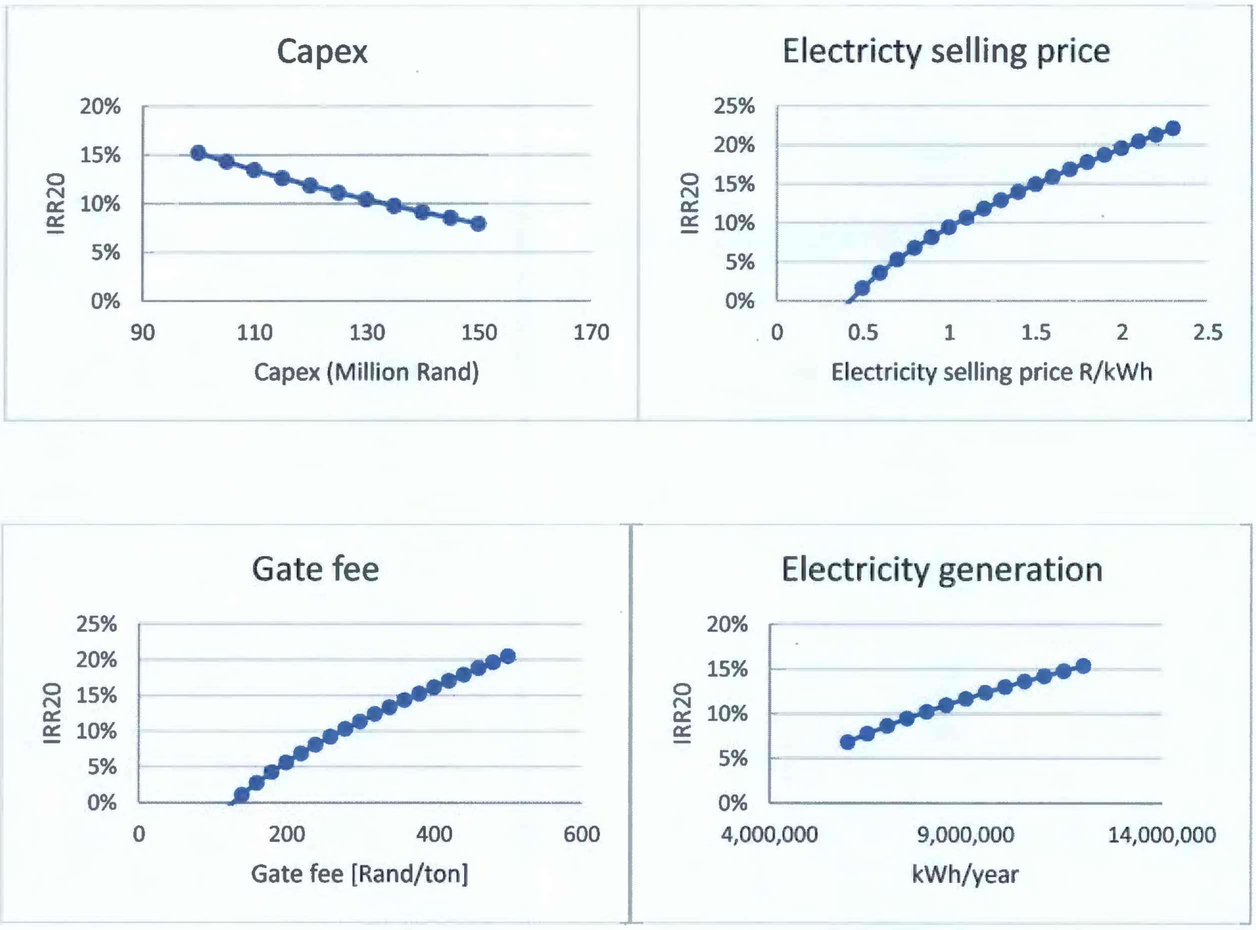


Figure 70: 5MW peak scenario sensitivity analysis

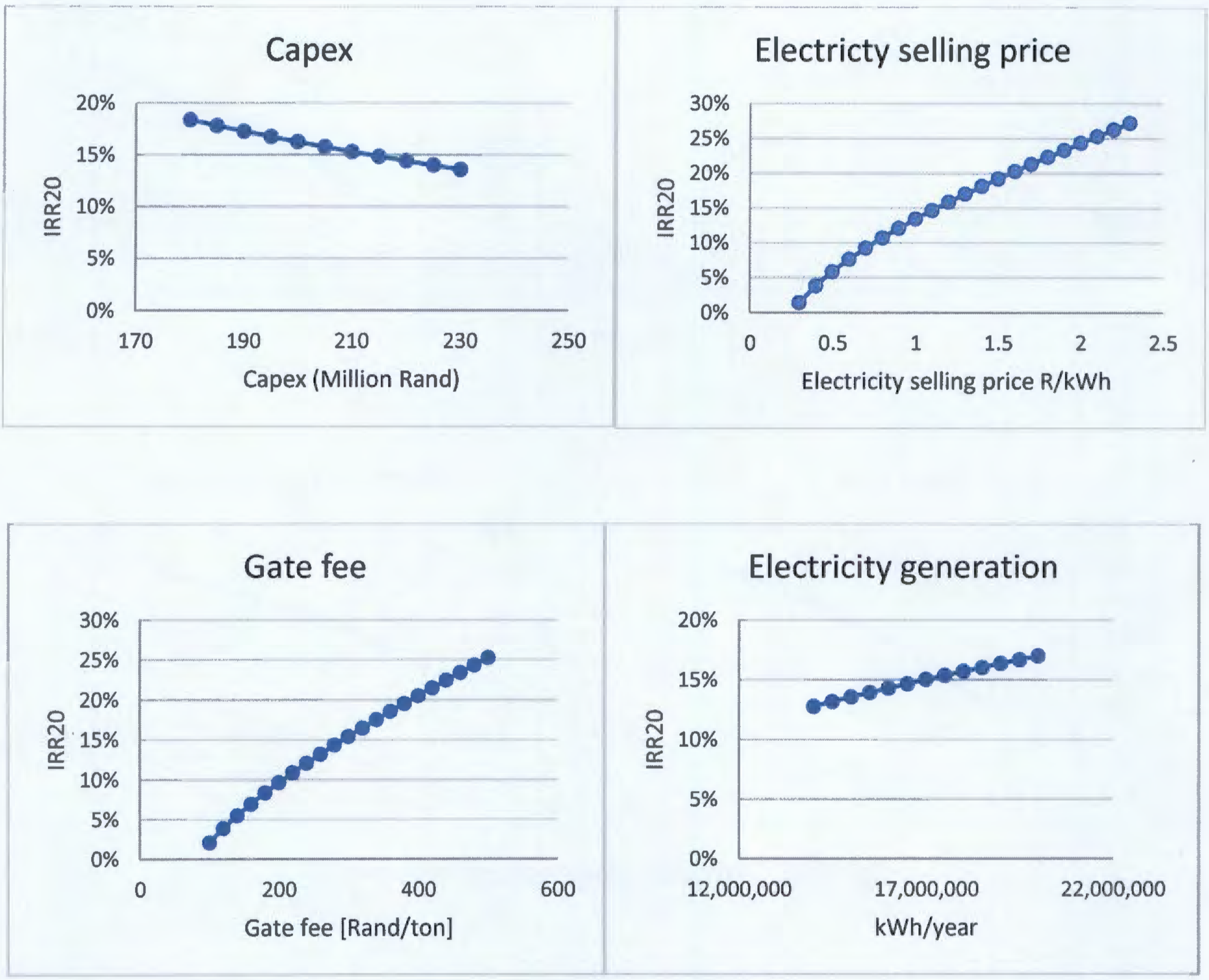


Figure 71: 10MW peak scenario sensitivity analysis

a. Capex sensitivity: none of the scenarios showed a strong sensitivity to Capex. It can be witnessed that the bigger the project is in terms of energy production, the less sensitive it is to capex variations. The 5MW peak and 2MW scenarios are the most sensitive to Capex, this is mainly due to their relative low amounts of electricity generated.
b. Electricity price sensitivity: all the scenarios shows medium sensitivity to electricity price. It can be witnessed that at 1 R/kWh, the sensitivity changes from linear to exponential – linear above 1 R/kWh and exponential below. The 5MW continuous and peak & standard scenarios show the least sensitivity to electricity price, from this it can be concluded that the more energy is generated the less sensitive the project is to the electricity price.
c. Gate fee sensitivity: all the scenarios shows medium to strong sensitivity to gate fees. It can be witnessed that at around 200 R/t, the sensitivity changes from linear to exponential – linear above 200 R/t and exponential below. Here again it can be concluded that the more energy is generated the less sensitive the project is to the gate fee.

d. Electricity generation sensitivity: All the scenarios shows a linear and weak to medium sensitivity to electricity generation. It can be witnessed that the continuous generation scenarios are the least sensitive followed by peak and standard and peak only, this is mainly due to the fact that in the peak and standard and peak only scenarios, electricity is generated in a limited but critical intervals and therefore any deviation from the planned production is effecting the business case. A correlation between this size of the project and its sensitivity to electricity generation can also witnessed, for example, the 5MW peak scenario is more sensitive to electricity generation than the 10MW peak one.

Table 35 below compars the different project scenario sensitivities by adding and subtracting 10% from all four key parameters. It can be seen that the chosen 5MW peak and standard scenario (highlighted in yellow) remains the most financially attractive when compared with other scenarios in the same kay parameters variation. The cells highlighted in red show all the cases where a negative variation to the key parameters of the selected scenario turns out to be less financially favourable then a positive variation in the same key parameter in other scenario. For example, a 10% increase in the 5MW P&S capex, makes this scenario less financially attractive then the case of a 10% decrease in the 5MW continues scenario capex and financially similar to the case of a 10% decrease in the 3MW continues scenario capex.

Overall it can be concluded from table 35 below that the chosen scenario is mostly more financially attractive under a sensitivity test of +/-10%, when compared with the other scenarios.

		IRR20					
	Scenario	2MW (c)	3MW (c)	5MW (c)	5MW (p&s)	5MW (p)	10MW (p)
Current IRR20		16%	18.5%	20.7%	22.8%	11.4%	15.5%
Capex	-10%	18%	21%	23%	25%	13%	17%
	,10%	14%	17%	20%	21%	10%	14%
Electricity selling price	-10%	15%	17%	19%	21%	10%	13%
	,10%	17%	19%	21%	24%	13%	17%
Gate fee	-10%	13%	16%	18%	20%	10%	13%
	,10%	18%	21%	24%	25%	13%	17%
Electricity generation	-10%	15%	17%	19%	22%	10%	14%
	,10%	17%	20%	22%	24%	12%	17%

Table 35: project scenarios sensitivity analysis comparison

5.4. Environmental results

As part of the assessment for the proposed biogas facility at AF, Chand Environmental Consultants visited the site on 5 November 2014. Following the site visit, a desk study was conducted accompanied by an interview with the Department of Environmental Affairs and Development Planning (DEA&DP): Land Use Management, Directorate DEA&DP: Waste Management Directorate, and City of Cape Town: Specialised Environmental Health: Air Quality Management. We conducted the interview together with Chand Environmental consultants on the 9th of December 2014 (Chand Environmental consultants, 2014). Below are the conclusions of the study which we are using in this study, please refer to appendix 2 for the full report.

- The site on the Foundry property is suitable for the development of a biogas facility as there are no environmental sensitivities located on the area earmarked for the development;
- Whilst areas of biodiversity importance surround the Foundry property, it is unlikely that the biogas plant will impact on biodiversity resources in the area;
- One combined Scoping and EIA process must be followed in order to obtain the required Environmental Authorization and Waste Management License. It is no longer possible for authorities to grant approval to apply a Basic Assessment in an instance where a Scoping and EIA process is triggered;
- The biogas plant will not require authorization in terms of legislation governing air quality, however an amendment may be required to the Foundry's current Air Emissions License. The need for the amendment, and the process for such amendment (if required) can only be confirmed by authorities subsequent to their further investigation of the matter;
- In addition to the Scoping and EIA process that must be undertaken by an independent Environmental Assessment Practitioner (Chand), the project consultants will have to apply to the City of Cape Town for a permit to discharge the treated effluent to sewer.
- Municipal building approvals should be feasible to obtain as no major obstacle was identified.
- NERSA gas generation license should be feasible to obtain as no major obstacle was identified.

5.5. GHG results

Calculating GHG emission reduction of the chosen waste to energy scenario

In this section a calculation of the GHG emission reduction for the chosen waste to energy scenario - 5MW peak and standard - will be presented. This will include emission reduction from OFMSW avoided from being landfilled, emissions from the biogas plant and emission reduction from fuel switch – using biogas to generate electricity instead of Eskom's electricity.

5.5.1. Emission reduction from OFMSW avoidance from landfilling

The chosen scenario uses 132,000 ton/year of MSW, out of which 60% is the OFMSW fraction, which is why in equation 17, this equal to 79,200 ton/year of OFMSW. The DOCi of OFMSW is 0.15 (IPCC, 2006). Cape Town's landfill biogas methane fraction used is 48.6% (IPCC, 2006). Therefore the methane emissions generated from landfilling the designated project feedstock, using equation 18 is 7,603 ton per year.

Considering the oxidation factor of 0.1 (IPCC, 2006; CoCT, 2011), this equates to 6,843 ton of methane emitted per year, from landfilling the designated project feedstock.

To convert the methane emissions to carbon dioxide emissions the methane global worming factor of 21 must be used, so the equivalent avoided carbon dioxide emissions is 143,700 ton per year.

5.5.2. Emission reduction from fuel switch

The chosen AF waste to energy scenario will utilize 28.2 GWh per year of electricity to replace Eskom's electricity.

Eskom's electricity generation carbon dioxide emission factor is 1.015 kg CO_2 per kWh (Letete et al., 2009).

Therefore, using equation 19, the carbon dioxide emission reduction for electricity switch is 42,265 ton per year.

5.5.3. Emissions from biogas activity

To calculate the emissions from the biogas production activity, biogas leakages and carbon dioxide emitted from the combustion of biogas need to be considered.

The expected biogas production is 38,400 m^3/day or using biogas density of 1.2 kg per m^3 (Deublein, 2011), is equal to 46 ton per day. The leakage factor used is 5% (IPCC, 2006) which results in 2.3 ton per day, out of which 60% is methane. To convert all the leakage emissions to carbon dioxide emission base, we must multiply the methane fraction of the leakages by its global worming factor of 21, which results in a total of 30 ton per day of carbon dioxide or 10,950 ton per year.

The emissions from the combustion of the biogas in the CHP unit are 0.9 Kg carbon dioxide per kWh of electricity generated (Cuéllar, 2008). Considering that the CHP unit will produce 31,360,000 kWh per year, including electricity for self-consumption, 28,224 ton of carbon dioxide per year will be emitted.

5.5.4. Total GHG emission reduction

The total emission reduction from the waste to energy project is the emission reduction from the OFMSW avoidance from landfilling, plus the emission reduction from fuel switch (Eskom's electricity), minus emissions from the biogas production activity, which amounts to 146,791 ton per year. Table 36 below summarizes the calculation.

Activity	CO2 emissions (ton/year)
Landfilling avoidance	143,700
Electricity switch	42,265
Biogas leakages	10,950
CHP emissions	28,224
Total	146,791

Table 36: project GHG emission summary

5.6. Remarks

The feasibility of proposed Atlantis Foundry waste to energy plant could be improved if the following issues are taken into account:

a. Atlantis is in a Special Economic Zone (SEZ): Atlantis was recently classified as an SEZ – meaning the government will provide significant tax incentives – 15% corporate tax instead of 28% and EIA process will be fast-tracked, making the pursuit of a waste to energy project even more attractive. However in a meeting in Cape Town held on the 14 November 2014 with the Green Cape (who facilitate the SEZ in Atlantis on behalf of the western Cape government), we were informed that final regulations for SEZ's in general and that Atlantis status as an SEZ is still to be concluded during the course of 2015 (Green Cape, 2014).
b. Grants: to improve the economic viability of waste to energy projects, investors and project developers can access green financing vehicles. For instance Atlantis Foundries could approach the DTI (Department of Trade and Industry) for renewable energy grants to improve project viability. Such grant can be in the range of 10 million Rand and can significantly improve the project feasibility (DTI, 2012).
a. Existing sand drying plant: in this study it was considered substituting the electricity used in the electrical sand drying plant with excess heat from the CHP unit. However, to be conservative, a very low price of 0.3 R/kWh was used. It is therefore important for AF to consider if the cost and benefits of excess heat from the waste to energy project may be greater then presented in this study.
b. New sand drying plant: AF intends to establish a new sand drying plant and this new plant could be designed taking into account the availability of waste heat from the envisaged waste to energy plant – and allow provision for future connection.
c. AD plant self-consumed electricity: For the purpose of this feasibility study, it was assumed that the self-consumed electricity price is similar to the off-take price for all categories. Once the project reaches detailed design stage, this could be optimized, to reduce the project electricity costs, by using self-consumed electricity at off-peak times and avoiding using electricity during peak times.
d. Carbon credit and Carbon tax: in this study the carbon dioxide emission avoidance were calculated, however carbon credits or future carbon tax savings were excluded from the financial modeling. Carbon tax is expected to start in South Africa in the next year or two and initial indications from Treasury are for a cost of about 120 R/ton (National Treasury, 2013). AF could already explore scenarios that consider this potential future financial benefit.

e. Refuse Derived Fuel (RDF): one of the byproducts of the discussed waste to energy project is RDF. The RDF can be a cost to the project if it needs to be dumped or an income if off-taken as an RDF. For the purpose of this study and to be conservative, it was assumed that all the RDF from the project would be dumped. Anaergia is in discussions with potential RDF off-takers in the area and found a high potential to establish an RDF off-take for the AF project (Anaergia, 2014). Such off-take will improve the project business case significantly.
f. On site solid waste: since AF has fairly low amounts of suitable solid waste (general waste) for the envisaged waste to energy project it wasn't considered in the waste to energy plant design and feasibility evaluation. However this waste could be easily used by the project and allow some cost savings on waste disposal and therefore this option should be further investigated, once the waste to energy project start to operate.
g. Public image: any of the waste to energy scenarios covered in this study could among the biggest waste to energy projects in Africa and definitely the biggest municipal waste to energy project. The construction of such project will attract large and positive, local and international public attention to Atlantis Foundries. BMW, in Pretoria is already half way in construction of its waste to energy biogas project, sized around 4 MW (Bio2Watt, 2014).
h. Long term future projections of AF production and the resulting energy consumption are difficult to determine. However this does not present a great challenge for a waste to energy project, since even at low production seasons (like 2013) or at idle times (weekends), AF has a fairly large average base load energy consumption of about 5 MW, that can easily justify a large waste to energy project.

Several methodological and data aspects of the study have some uncertainties. These includes the following:

a. Compost off-take: the approach of assuming that compost will be off-taken by neighboring farmers may be perceived as too optimistic, interviewing several farmers in the project area to confirm this assumption would have led to more accurate financial and technical feasibility results.
b. Renewable electricity price: the methodology used to determine the renewable electricity price could have been done more accurately if AF historical electricity consumption profile was considered and using a weighted average to determine the weight of each tariff in the average tariff calculation.
c. Carbon credit and carbon tax: neglecting carbon credit and carbon tax from the feasibility model doesn't reflect a very possible future scenario for the project. Though this approach is the more conservative one, considering the benefits of the two would have provided a better understanding of the project potential.
d. GHG reduction calculation: though the methodology used to calculate the GHG emission reduction was obtained from literature (and described in the literature review chapter), using the United Nations (UN) Clean Development Mechanism (CDM) would have yield more relevant results, especially concerning Carbon Credit and Carbon tax potential financial benefits.

6. Conclusions

This study has shown that it is technically and economically feasible to establish a large scale MSW AD to energy facility linked to a specific industrial load in Cape Town, South Africa. The results also show that all the selected project scenarios are technically feasible, legally achievable and financially feasible. Given the current electricity tariffs in South Africa, the evaluation has shown that the most attractive energy generation scenario is to establish a waste to energy plant at a scale of 5MW and operate it as a peaking as well as standard generation plant. Thus the "peak and standard" scenario was found to be optimal economically and has a payback time of 5.2 years, twenty years IRR of 23%, an NPV of about 316 million Rand, which exceed Antlatis Foundry minimum project feasibility requirements. Using 132,000 tonnes of waste, the facility is designed to produce about 1,600 m^3 of biogas per hour and generate 28.2 GWh of electricity.

All the other assessed waste to energy project scenarios were also found to be technically feasible when considering the availability of feedstock, access and siting of the facility, electrical interconnection and loading demands of the main consumer of the energy output – Atlantis Foundry load.

Antlatis Foundry provides a ready market for the facility's electricity and heat output as its continuous and intensive mode of operation and high energy demand presents a continuous and large renewable energy off-take opportunity for a waste to energy project. Thus a precondition for the successful deployment of waste to energy technologies is the availability of continuous and large energy off-take market for the generated energy.

Adequate waste is available from the waste to energy facility, enough waste is available to provide the required 210,000 tonnes per year for a 5 MW continuous. The continuous plant is less competitive compared to the 5 MW peak and standard plant as the investment returns are weaker for that scenario. Thus avoiding off-peak generation could improve the business case. However, the waste to energy plants could provide base load to the electricity supply system unlike other renewables such as solar and wind, and this could be supported by policy to encourage investors to establish continuous plants. The peak generation scenarios are less favourable economically due to the poor return on investment as their operation is restricted to only a few peak hours.

The proposed plant is also attractive as it is to be located close to Vissershok landfill (one of the biggest landfills in the Western Cape) and therefore provides a key favorable attribute for a waste to energy project, the shorter the transportation distance from source of waste to energy conversion facility, the better the economics of the value chain. Thus proximity of a waste to energy facility to large landfills improves the feasibility of the waste to energy project.

There is therefore a strong business case for establishing the waste to energy facility at the Atlantis Foundry site, apart from the additional environmental benefits. AF's relatively high electricity consumption during peak and standard tariff times, strongly supports the business case of a waste to energy project. Hence, similar projects should be investigated with other large electricity consumers with high peak and standard demand. The chosen 5MW P&S scenario will result in a GHG emission avoidance equal to 150 kiloton of CO_2 per year, which could strengthen the project case and may result in significant financial benefits in the future in terms of carbon credits. AF current industrial permits (including air emission license) makes securing of environmental and legal permits for the waste to energy project easier. Thus heavy industries are good candidates for waste to energy projects since they have established environmental permissions processes.

7. Recommendation and the way forward

a. Separation at source is not considered in this study, though it is recommended to include the impact it may have in future work, since separation at source may improve significantly the project techno economic feasibility.

b. The 5 MW peak and standard project scenario has the strongest business case and the lowest sensitivity, therefore it is recommended for AF to pursue it. However, the 2-5 MW continuous scenarios also show a good business case and low sensitivities, so pending on Atlantis interpretation of this study and internal considerations, if a smaller project (other than the 5MW peak and standard) is desired, it is recommended to pursue a 2 or 3 MW continuous scenario could also be implemented.

c. Load shedding: Waste to energy projects such as the one proposed in this study could go a long way in meeting the national electricity shortfall. The extensive load shedding experienced in 2015 (and further load shedding expectation into the future) requires that Eskom's (the utility provider) promote diversified electricity generation, especially in light of large industrial consumers' (such as AF) need for continuous and stable energy supplies.

d. LPG: substituting LPG with biogas was not considered in this study, due to the relative low energy consumption in comparison to electricity. However once the project advances further, it is recommended to consider LPG substitution for the holding puts and the lining station.

e. EIA: given the very promising feasibility of a waste to energy project in Atlantis foundries and the long lead times for EIA's (at list 300 days) (DEA, 2013), it is recommend that AF considers starting with the EIA as soon as possible. Such bureaucratic processes can be a major barrier to the implementation of waste to energy projects and can lead to abandonment of projects.

f. Waste: feedstock is a key to unlock any waste to energy project, given the promising feasibility of a waste to energy project at AF, it is strongly recommend for AF to engage with potential waste suppliers and establish the volumes and nature of waste that they can secure for their plants. It is also recommended that a long term contract be secured to ensure the availability of adequate volumes of waste into the future.

g. AF sewage and other biodegradable waste: Additional waste could be mobilized around Atlantis Foundry and this includes sewage waste and other types of biodegradable waste. It is recommended that at the detailed design stage of the project, AF sewage waste be treated via the AD plant, and this could potentially improve the project economics, albeit marginally.

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Appendix 1: AF 2014 base load and average power consumption graphs, on a monthly basis

January to September 2014

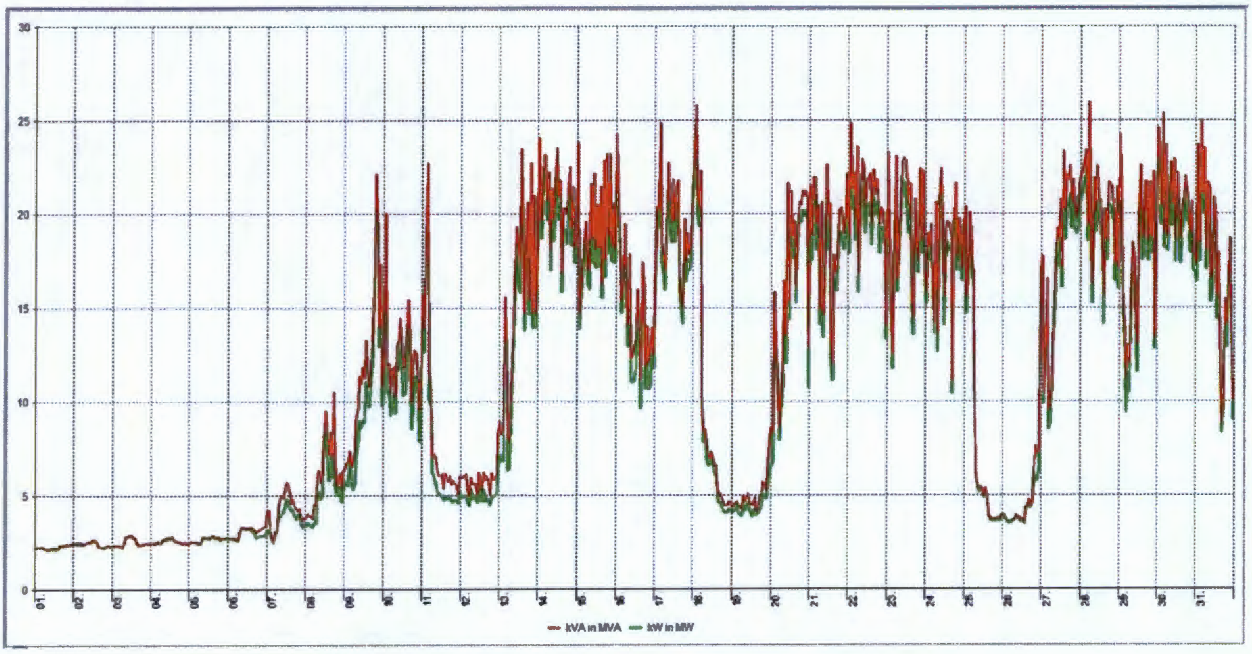


Figure 1: Atlantis Foundries January 2014 electricity power consumption

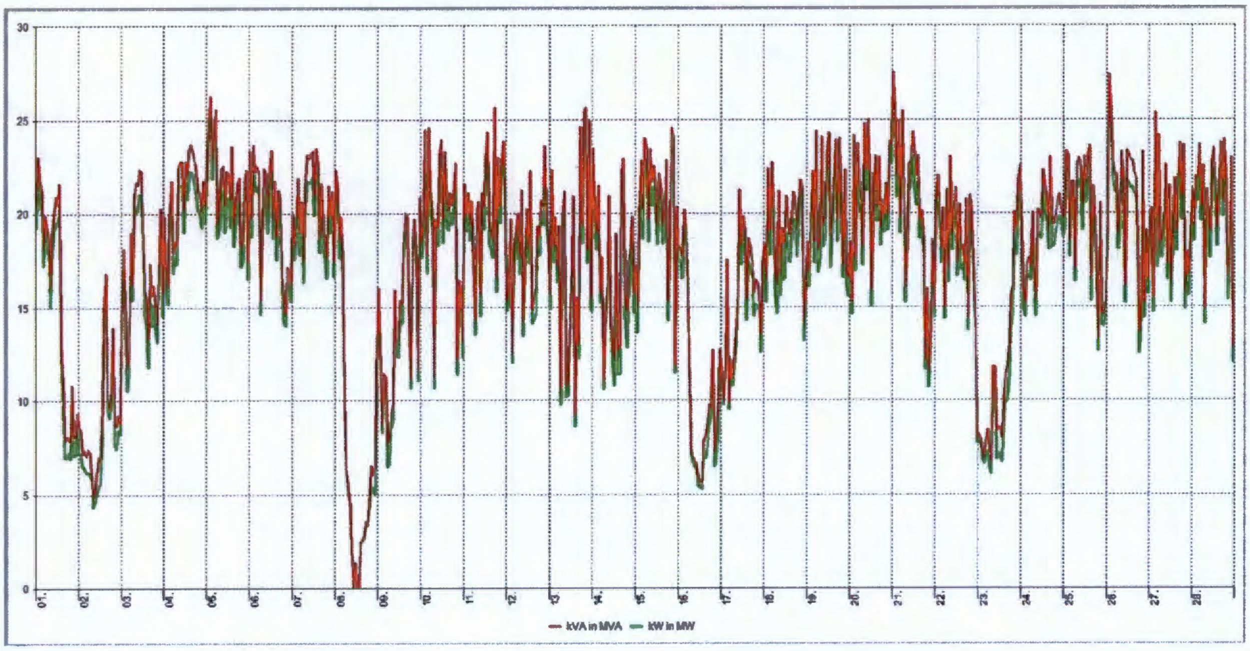


Figure 2: Atlantis Foundries February 2014 electricity power consumption

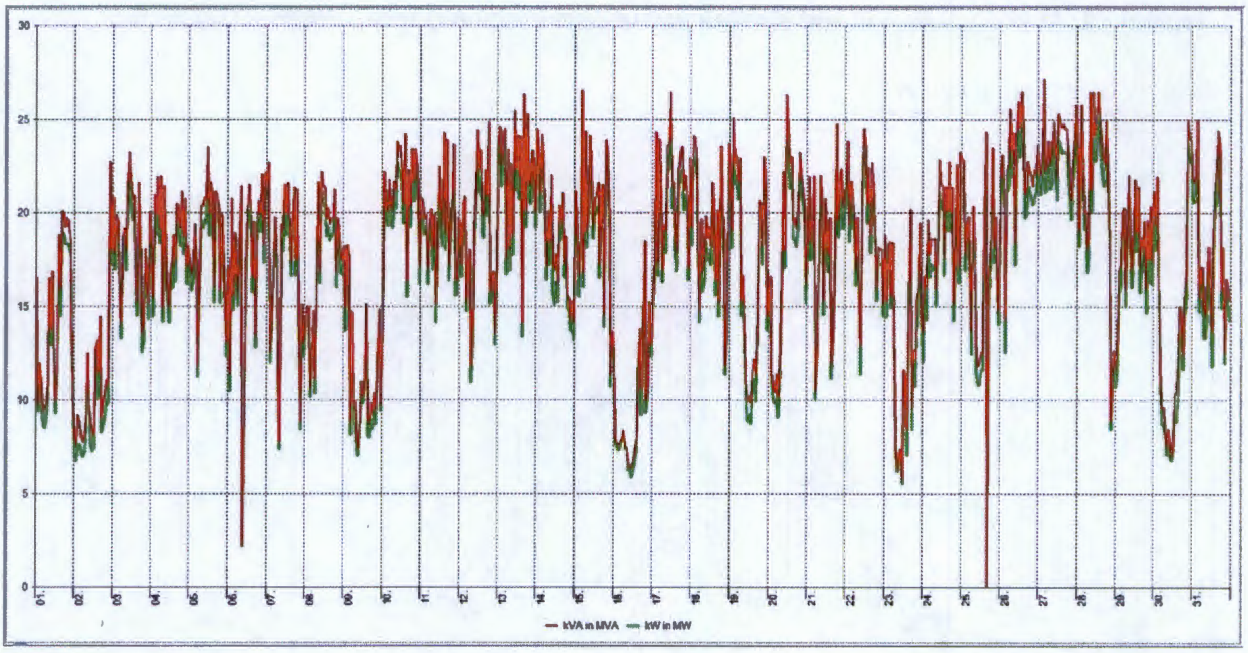


Figure 3: Atlantis Foundries March 2014 electricity power consumption

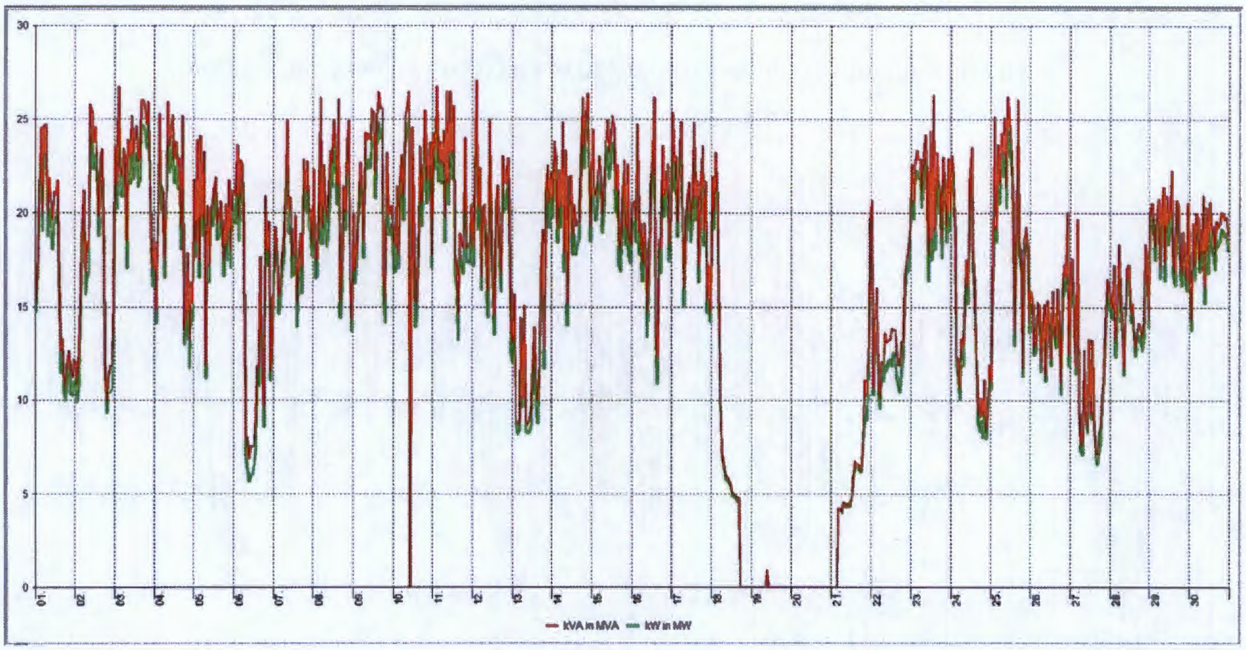


Figure 4: Atlantis Foundries April 2014 electricity power consumption

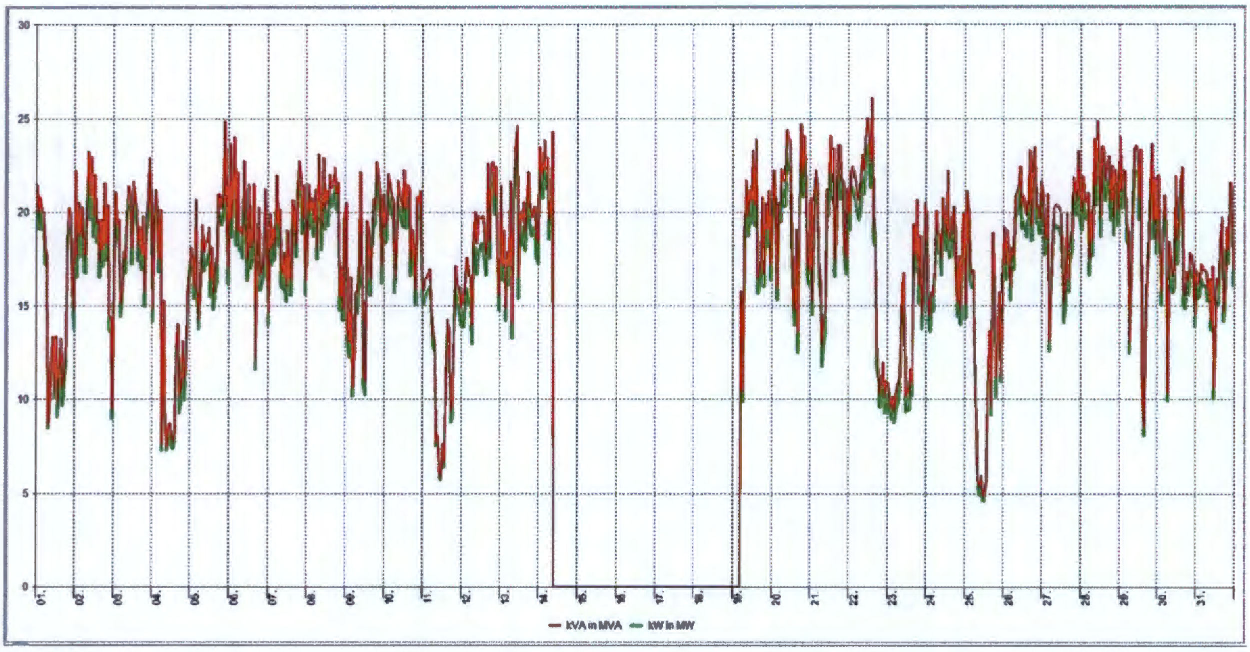


Figure 5: Atlantis Foundries May 2014 electricity power consumption

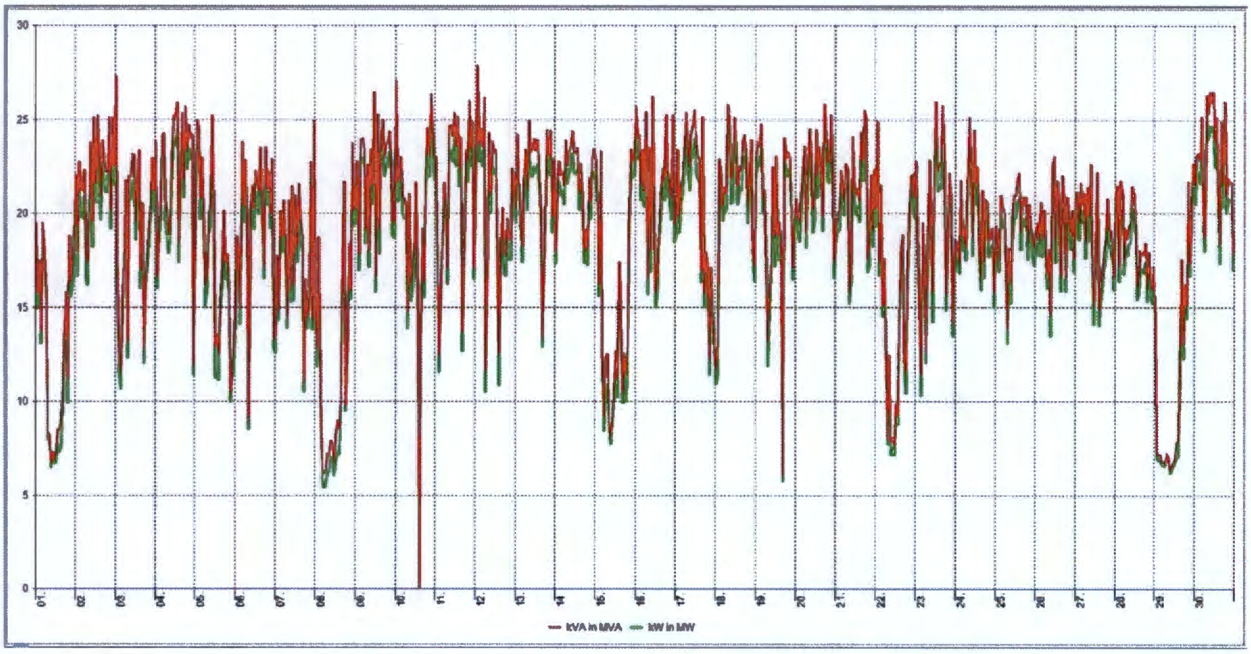


Figure 6: Atlantis Foundries June 2014 electricity power consumption

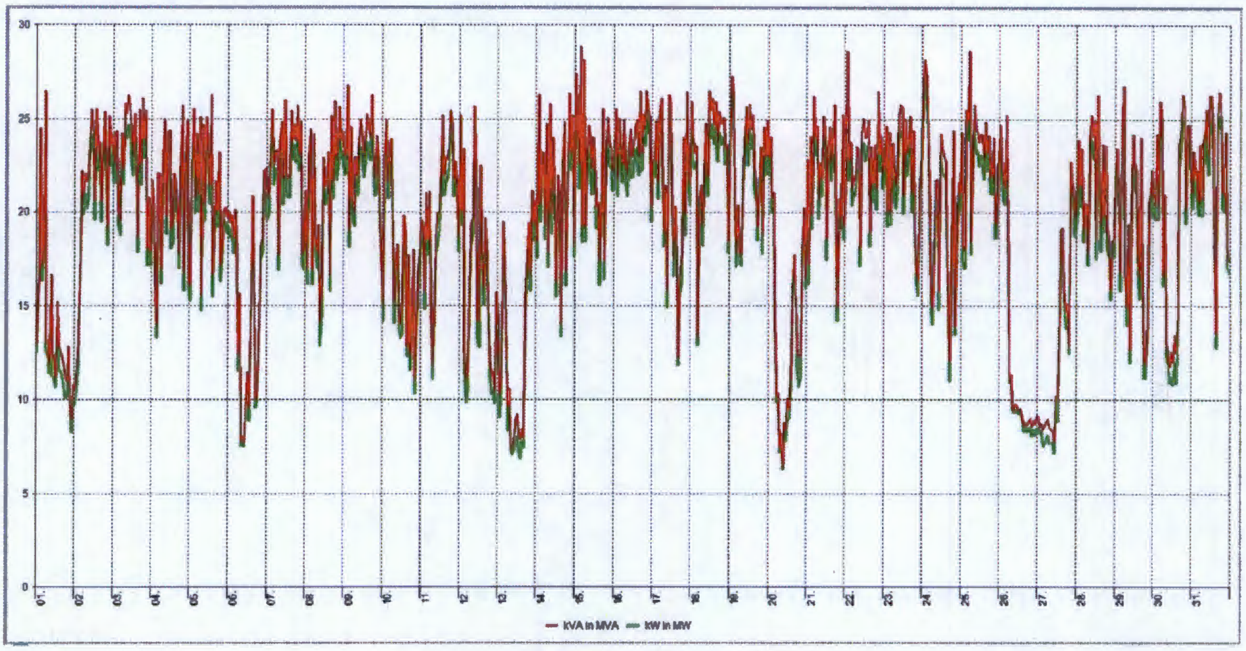


Figure 7: Atlantis Foundries July 2014 electricity power consumption

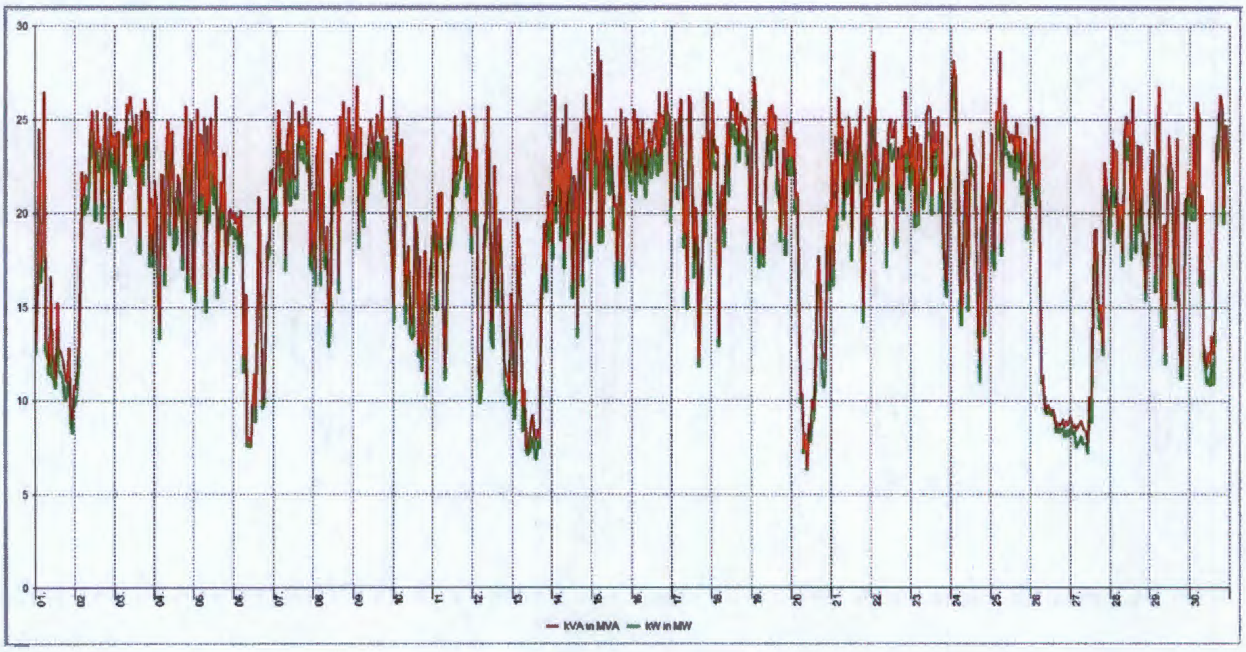


Figure 8: Atlantis Foundries August 2014 electricity power consumption

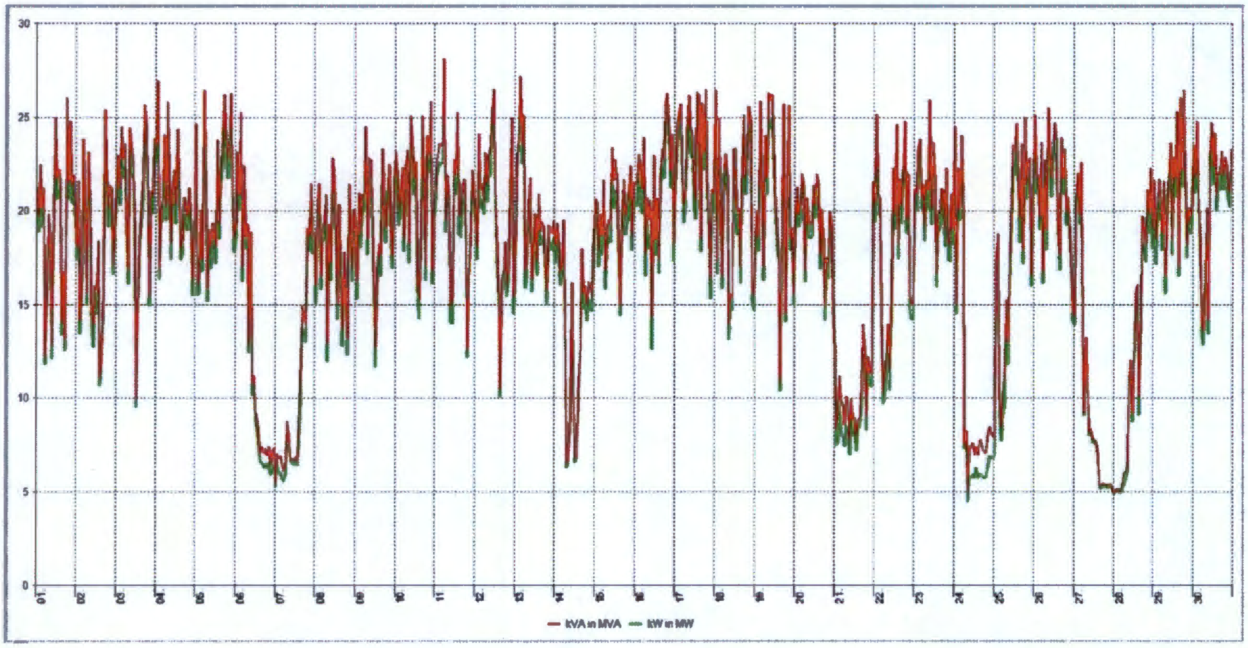


Figure 9: Atlantis Foundries September 2014 electricity power consumption

Appendix 2: Atlantis Foundries MSW AD project environmental feasibility – a desktop study

CHAND

12 December 2014

PHASE 1 REPORT: ATLANTIS BIOGAS PROJECT

INTRODUCTION:

As part of the phase 1 assessment for a proposed biogas facility at the Atlantis Foundry, Chand Environmental Consultants was appointed to carry out an investigation to determine the legislative requirements in order to obtain the necessary environmental development rights. The investigation entailed a site visit, a desktop study and analysis of available environmental information, a legislative review as well as liaison with relevant environmental authorities so as to determine the way forward.

FINDINGS:

a) Site visit

The site visit conducted on 5 November 2014 was undertaken with a view to investigate the environmental context of the proposed location of the facility on the Foundry property and to get a sense of potential environmental sensitivities on the site and within the surrounding area. The site walkabout revealed two possible locations for the siting of the biogas facility, with the one located within the Business Park area being clearly preferred from a logistical perspective. From an environmental perspective, both sites are equally suited for development, given that no environmental sensitivities were observed in either of these locations. Both areas are covered with remnants of corn fields, presumably from historical farming activities in the area. A low level of alien invasive species (such as Port Jackson and Patterson's Curse) were also present on both sites, noting however that evidence of regular alien clearing was observed to prevent the spreading of these invasive species. Land use beyond the property boundaries include industrial development as well as significant vacant land with very high levels of alien invasion and no aquatic or terrestrial sensitivities were noted during the visit.

b) Desktop study

A desktop study included the review of maps for the area contained in the Biodiversity GIS system as well as the Environmental Management Framework for the area contained in the City of Cape Town: Blaauwberg District Plan (2012).

Based on the information available, it appears as though the entire Foundry property has already been designated as industrial development, and as such, is excluded from environmental sensitivity mapping. This means that the site itself is not indicated as an area that will be subject to potential impact from development. The majority of the undeveloped areas surrounding the site are however included in the map of potential areas of impact, which suggests that, despite the high levels of alien infestation on the vacant land in the area, there are biodiversity resources off the site in question that must be protected. Owing to the nature of biogas installations, it is however unlikely that the operations of the facility will impact on areas of biodiversity importance that surround the Foundry property.

c) Legislative review:

There are a number of environmental legislative pieces that apply to biogas facilities. These are discussed below.

- National Environmental Management Act (Act No. 107 of 1998) (NEMA):

On 8 December 2014, new Environmental Impact Assessment (EIA) Regulations were promulgated in terms of NEMA. These regulations contain new Listed Activities that would trigger the need for Environmental Authorisation as well as the process requirements in order to obtain such an authorisation.

It is understood that as a minimum, 1050 m^3 of biogas will be stored on the site at any given time. It is further understood that there will be an element of purification of the gas, as sulfur will be removed. It should be noted that the purification of gas, regardless of the nature of such purification is considered "processing" of gas in terms of the law. As such, the following Listed Activities will (as a minimum) apply to the biogas installation:

> ***Listing Notice 2 (GNR 984) Activity No 4:*** *The development of facilities or infrastructure, for the storage, or storage and handling of a dangerous good, where such storage occurs in containers with a combined capacity of more than 500 cubic metres.*

> ***Listing Notice 2 (GNR 984) Activity No 5:*** *The development and related operation of facilities or infrastructure for the refining, extraction or processing of gas, oil or petroleum products with an installed capacity of 50 cubic metres or more per day.*

As activities listed in Listing Notice 2 are triggered, a Full Scoping and EIA process must be applied in order to obtain Environmental Authorisation.

- National Environmental Management: Waste Act (Act No. 59 of 2008) (NEM:WA):

Listed Activities promulgated in terms of NEM:WA may not commence in absence of a Waste Management Licence. It is understood that as a minimum, approximately 280t of organic waste will be processed on a daily basis in order to produce the biogas to generate electricity. This is considered 'treatment of waste' in terms of NEM:WA. As such, the following NEM:WA Listed Activities will (as a minimum) be triggered:

> ***GNR 921, Category B, Activity No 6:*** *The treatment of general waste in excess of 100 tons per day calculated as a monthly average, using any form of treatment.*

> ***GNR 921, Category B, Activity No 10:*** *The construction of a facility for a waste management activity listed in Category B of this Schedule.*

As activities listed in Category B are triggered, a Full Scoping and EIA process must be applied in order to obtain a Waste Management Licence.

- Local by-laws:

A number of City of Cape Town bylaws specify the need for permits in respect of specific environmental aspects. Of relevance to the biogas facility is the need for a 'Discharge to sewer' permit, for the release of treated effluent to the sewer system. The minimum requirements in terms of the quality of the effluent are specified in the City's Wastewater and Industrial Effluent By-law (2013), however it should be noted that the permit may contain conditions over and above the minimum requirements.

d) Meeting with authorities

With a view to get confirmation on the legislative requirements, a meeting was held with relevant authorities, which included officials representing the following departments:

- Department of Environmental Affairs and Development Planning (DEA&DP): Land Use Management Directorate
- DEA&DP: Waste Management Directorate
- City of Cape Town: Specialised Environmental Health: Air Quality Management

During the meeting, it was confirmed that both an Environmental Authorisation and a Waste Management Licence are required for the establishment of a biogas facility. The scale of the facility necessitates that a full Scoping and EIA process be followed in order to obtain these approvals. In terms of the new regulations, one combined process must be followed to attain the environmental development rights. Whilst the 2010 EIA Regulations allowed, in some instances, for the process requirement to be scoped down from Scoping and EIA to a Basic Assessment, this is no longer possible under the newly promulgated 2014 EIA Regulations. This was verified with the authorities during the meeting.

It was further confirmed that no activities in terms of the National Environmental Management: Air Quality Act (NEM:AQA) will be triggered, and as such, an Air Emission Licence is not required. It was however indicated that the Foundry's existing Air Emission Licence might need amendment as other materials will be utilised in the generation of energy sources for the Foundry. The need for such an amendment will however need further investigation by the air quality authorities and it was indicated that a decision in this regard can be expected early in 2015.

CONCLUSIONS:

In summary, the following conclusions are drawn from the phase 1 environmental investigation:

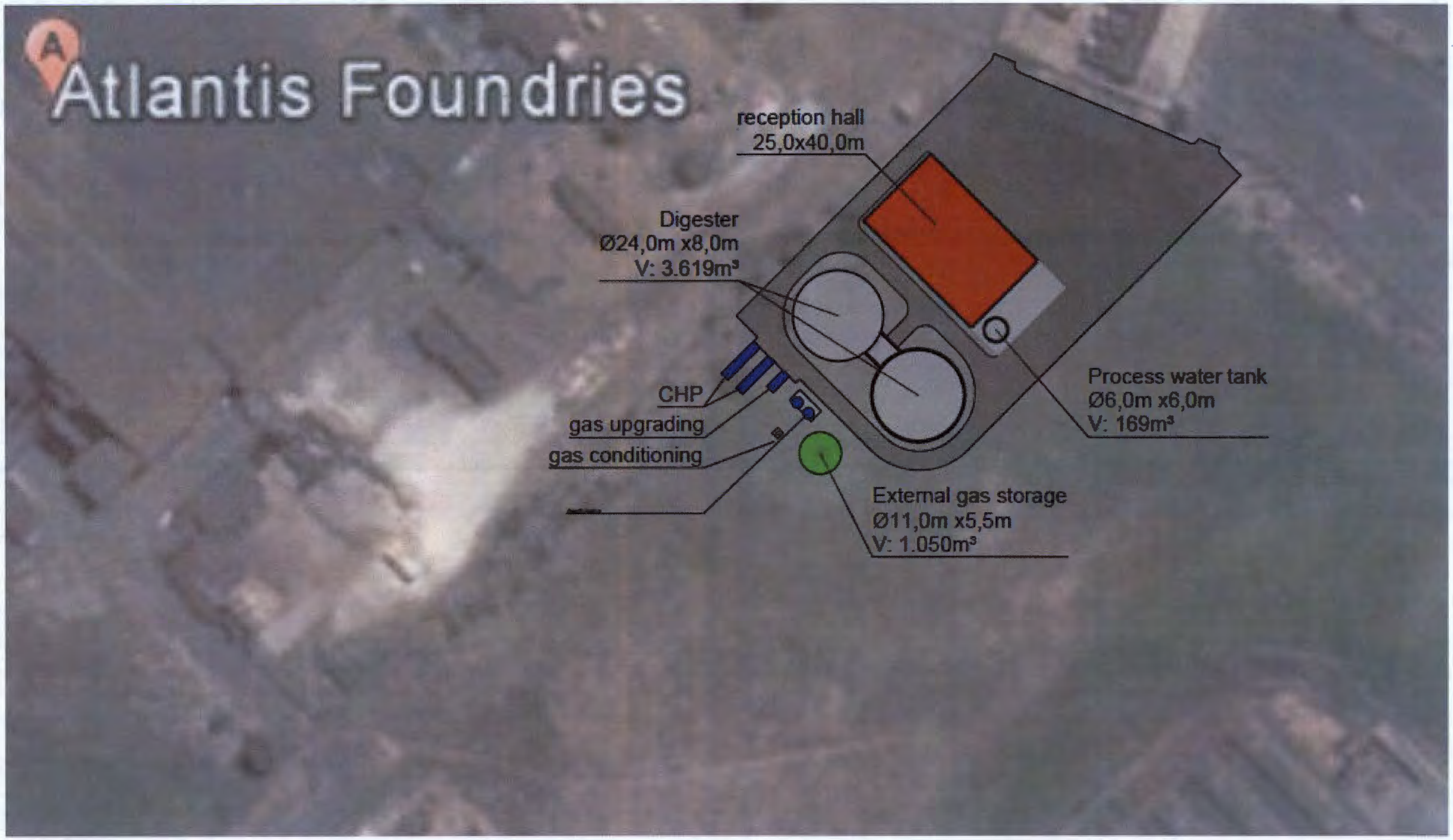
- The site on the Foundry property is suitable for the development of a biogas facility as there are no environmental sensitivities located on the area earmarked for the development;

- Whilst areas of biodiversity importance surround the Foundry property, it is unlikely that the biogas plant will impact on biodiversity resources in the area;

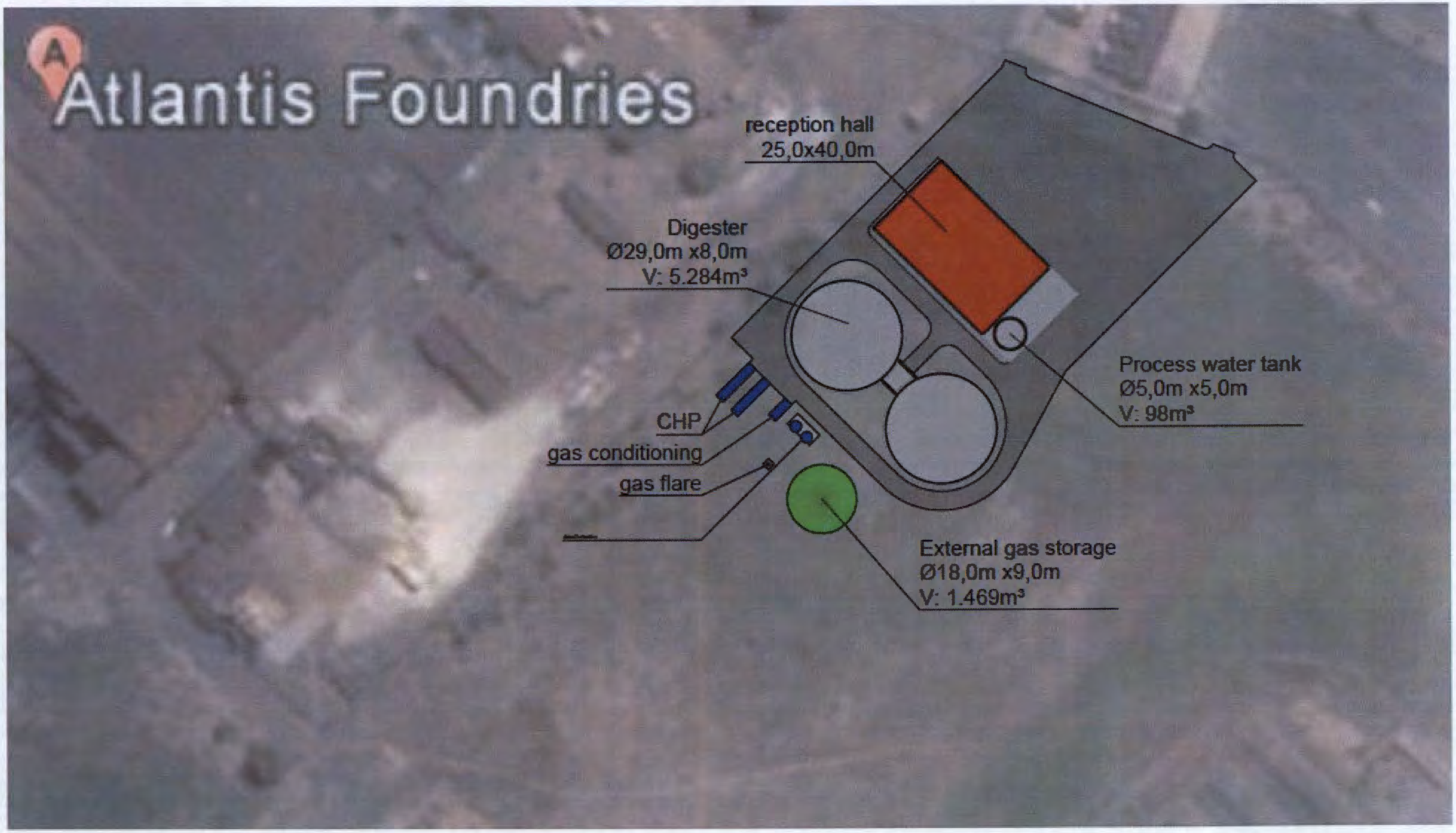
- One combined Scoping and EIA process must be followed in order to obtain the required Environmental Authorisation and Waste Management Licence. It is no longer possible for authorities to grant approval to apply a Basic Assessment in an instance where a Scoping and EIA process is triggered;

Appendix 3: AF waste to energy project scenario layouts

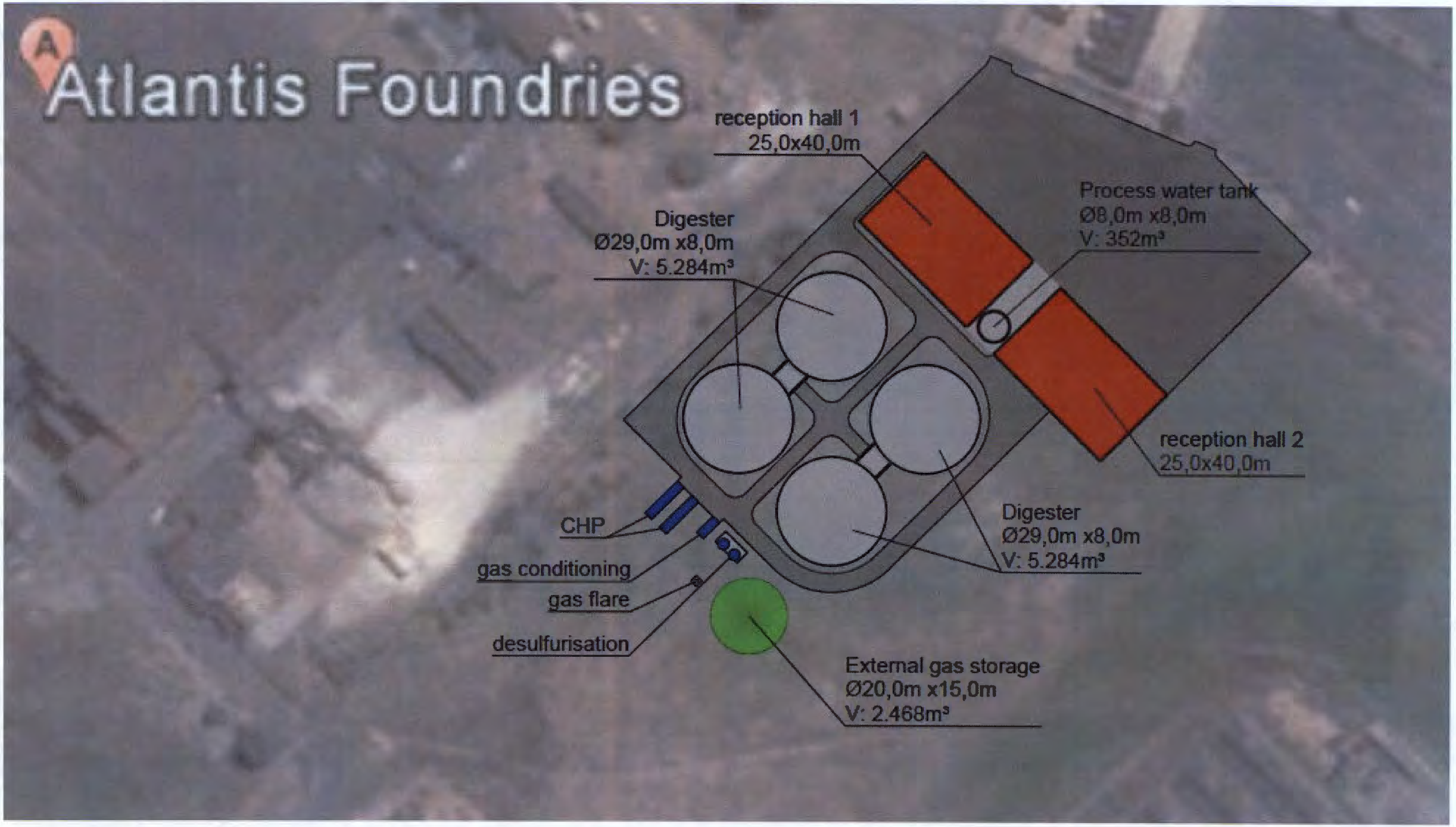
2MW



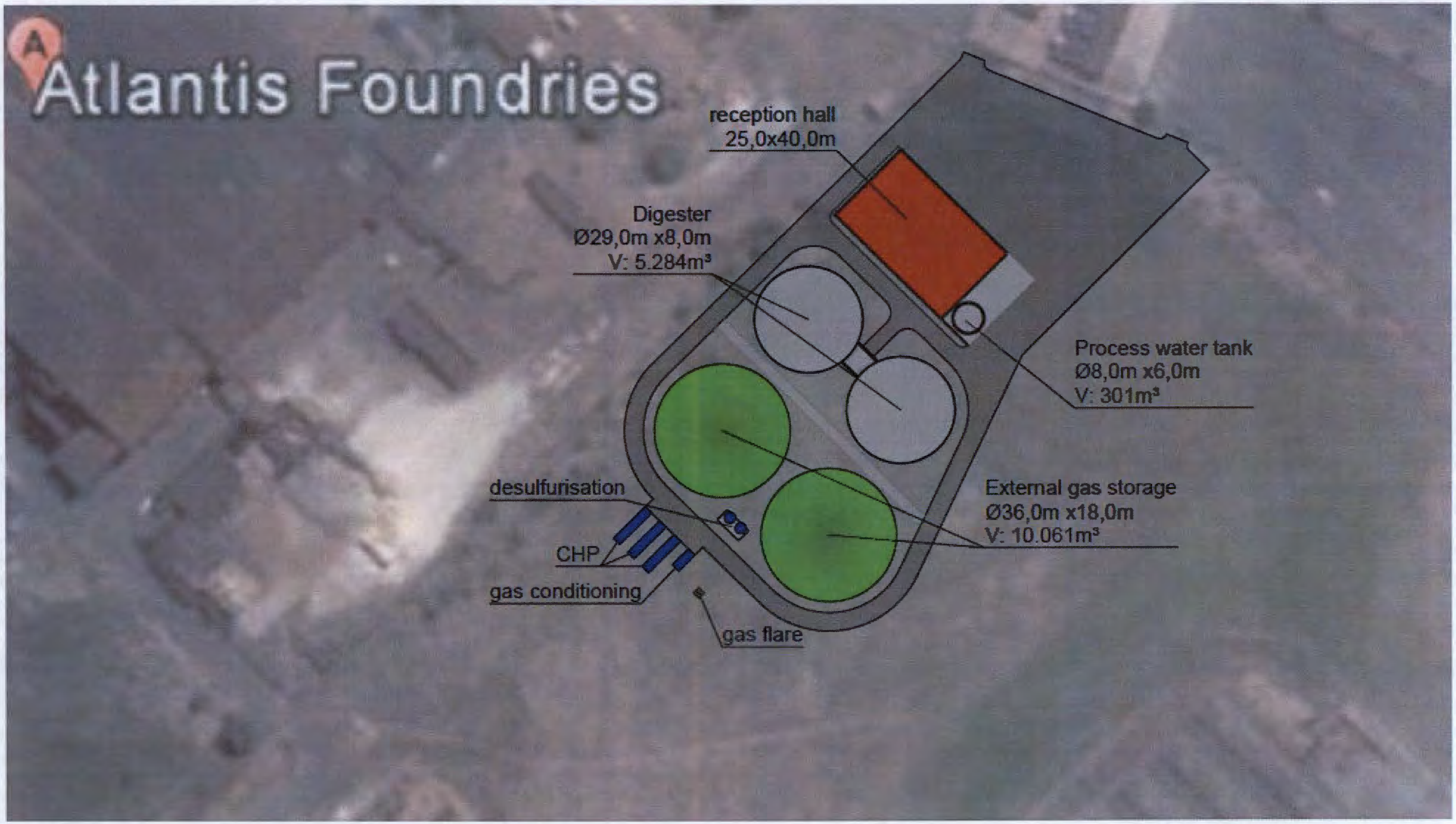
3MW


Atlantis Foundries
reception hall
25,0x40,0m
Digester
Ø29,0m x8,0m
V: 5.284m^3
Process water tank
Ø5,0m x5,0m
V: 98m^3
CHP
gas conditioning
gas flare
External gas storage
Ø18,0m x9,0m
V: 1.469m^3

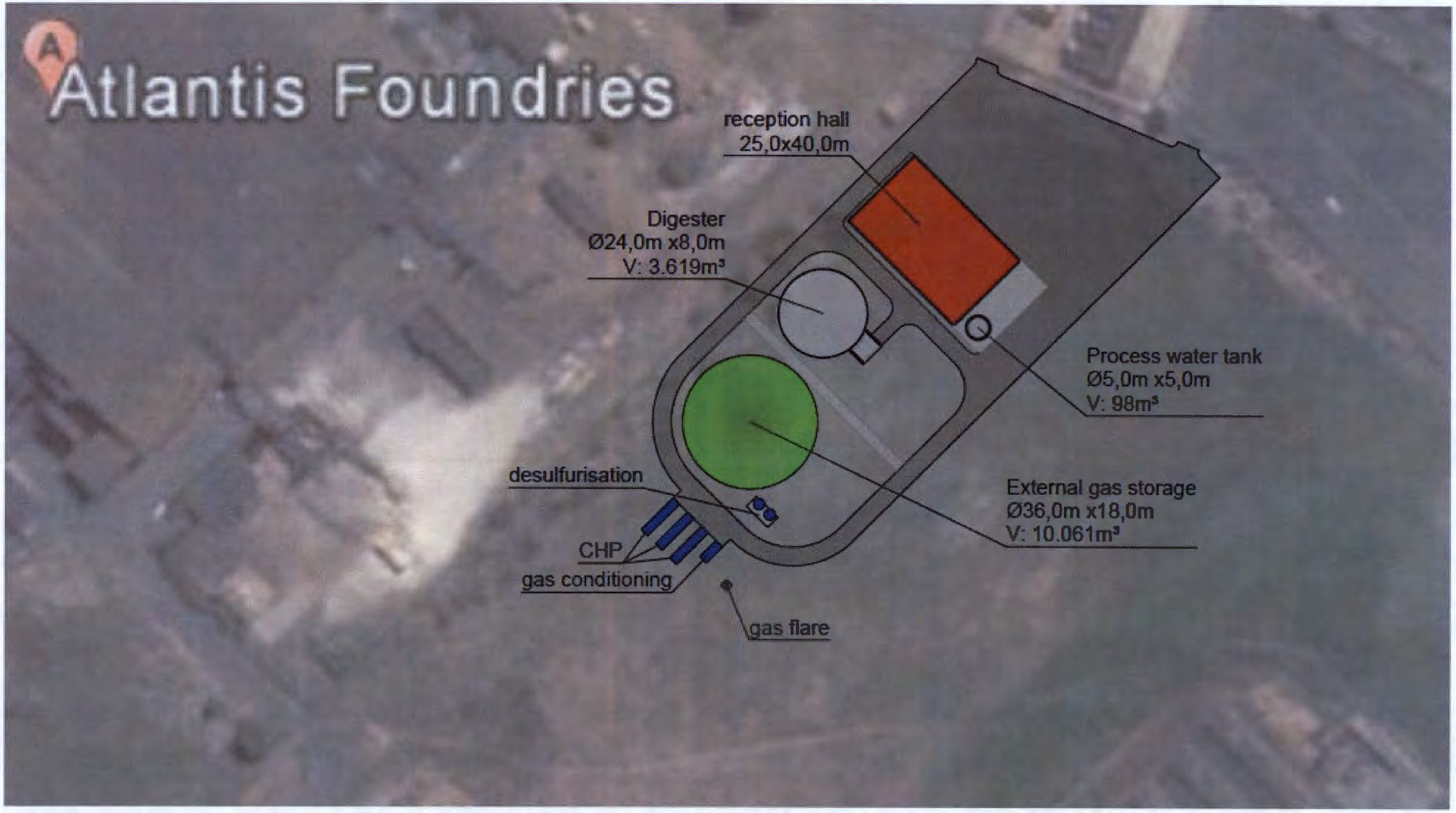
5MW (C)


Atlantis Foundries
reception hall 1
25,0x40,0m
Process water tank
Ø8,0m x8,0m
V: 352m³
Digester
Ø29,0m x8,0m
V: 5.284m³
reception hall 2
25,0x40,0m
CHP
gas conditioning
gas flare
desulfurisation
Digester
Ø29,0m x8,0m
V: 5.284m³
External gas storage
Ø20,0m x15,0m
V: 2.468m³

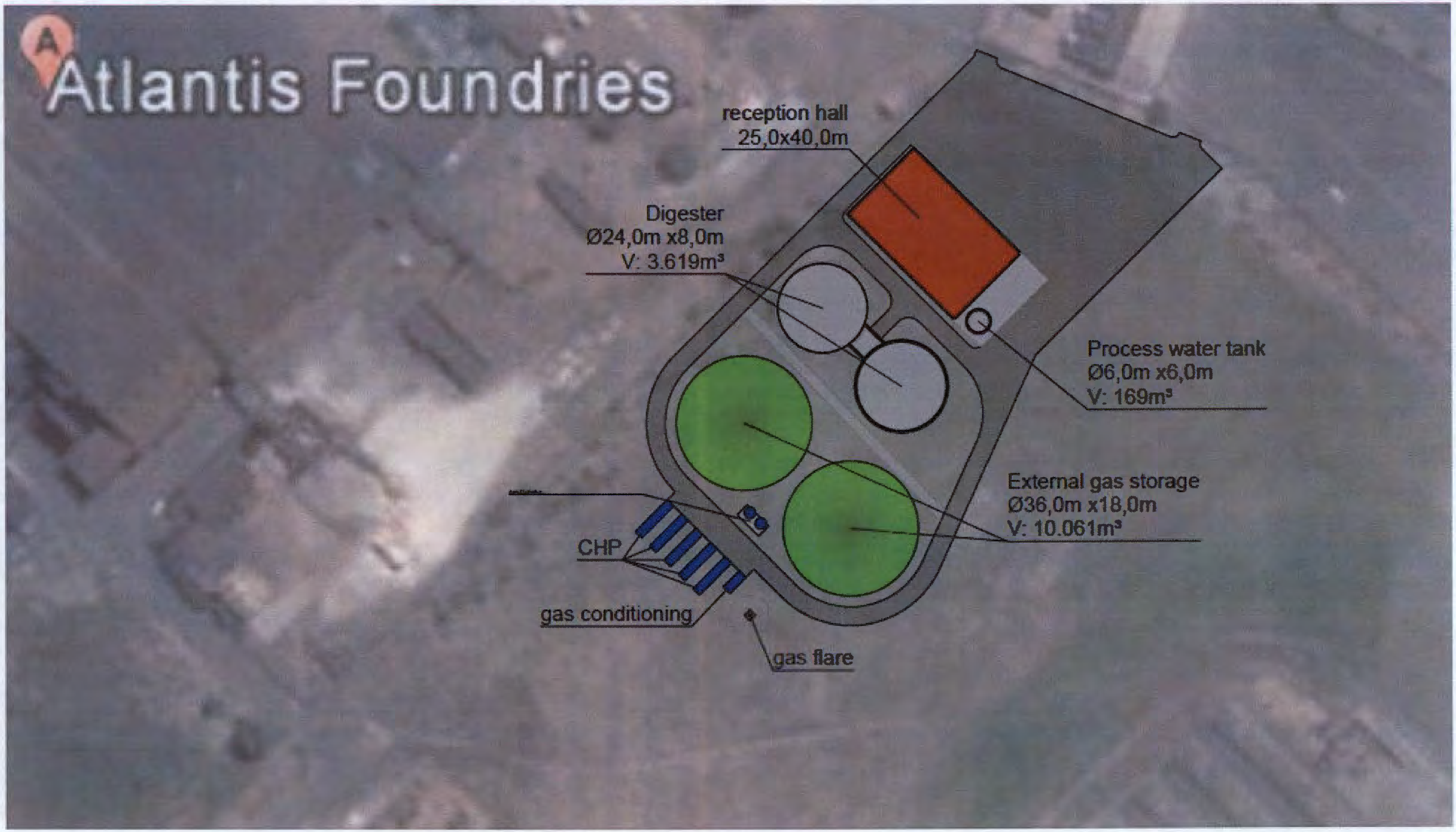
5MW (P & S)


Atlantis Foundries
reception hall
25,0x40,0m
Digester
Ø29,0m x8,0m
V: 5.284m³
Process water tank
Ø8,0m x6,0m
V: 301m³
External gas storage
Ø36,0m x18,0m
V: 10.061m³
desulfurisation
CHP
gas conditioning
gas flare

5MW (P)

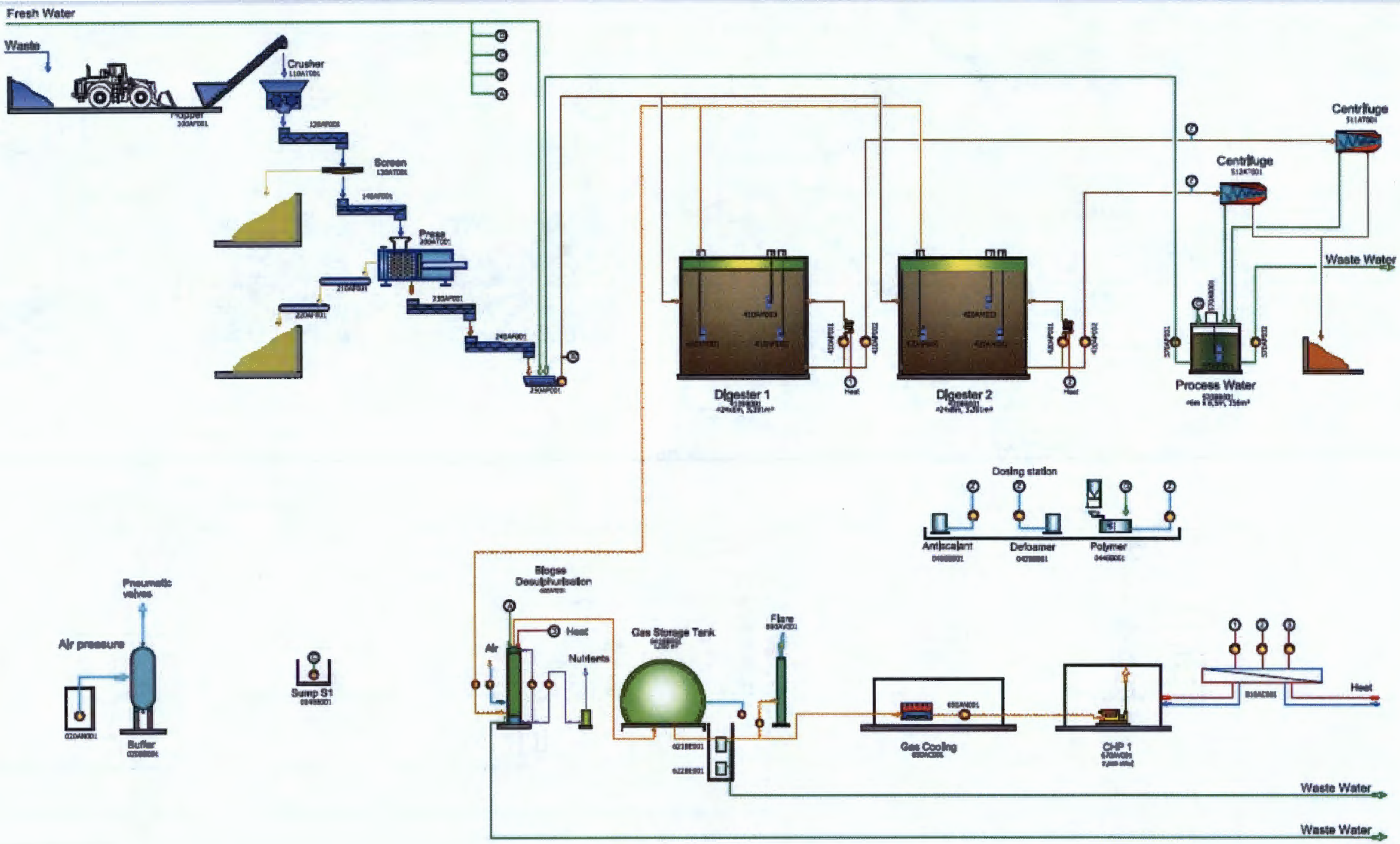

Atlantis Foundries
reception hall
25,0x40,0m
Digester
Ø24,0m x8,0m
V: 3.619m³
Process water tank
Ø5,0m x5,0m
V: 98m³
desulfurisation
External gas storage
Ø36,0m x18,0m
V: 10.061m³
CHP
gas conditioning
gas flare

10MW (P)


Atlantis Foundries
reception hall
25,0x40,0m
Digester
Ø24,0m x8,0m
V: 3.619m³
Process water tank
Ø6,0m x6,0m
V: 169m³
External gas storage
Ø36,0m x18,0m
V: 10.061m³
CHP
gas conditioning
gas flare

Appendix 4: Atlantis Foundries waste to energy project scenarios process flow diagram (PFD)

2MW



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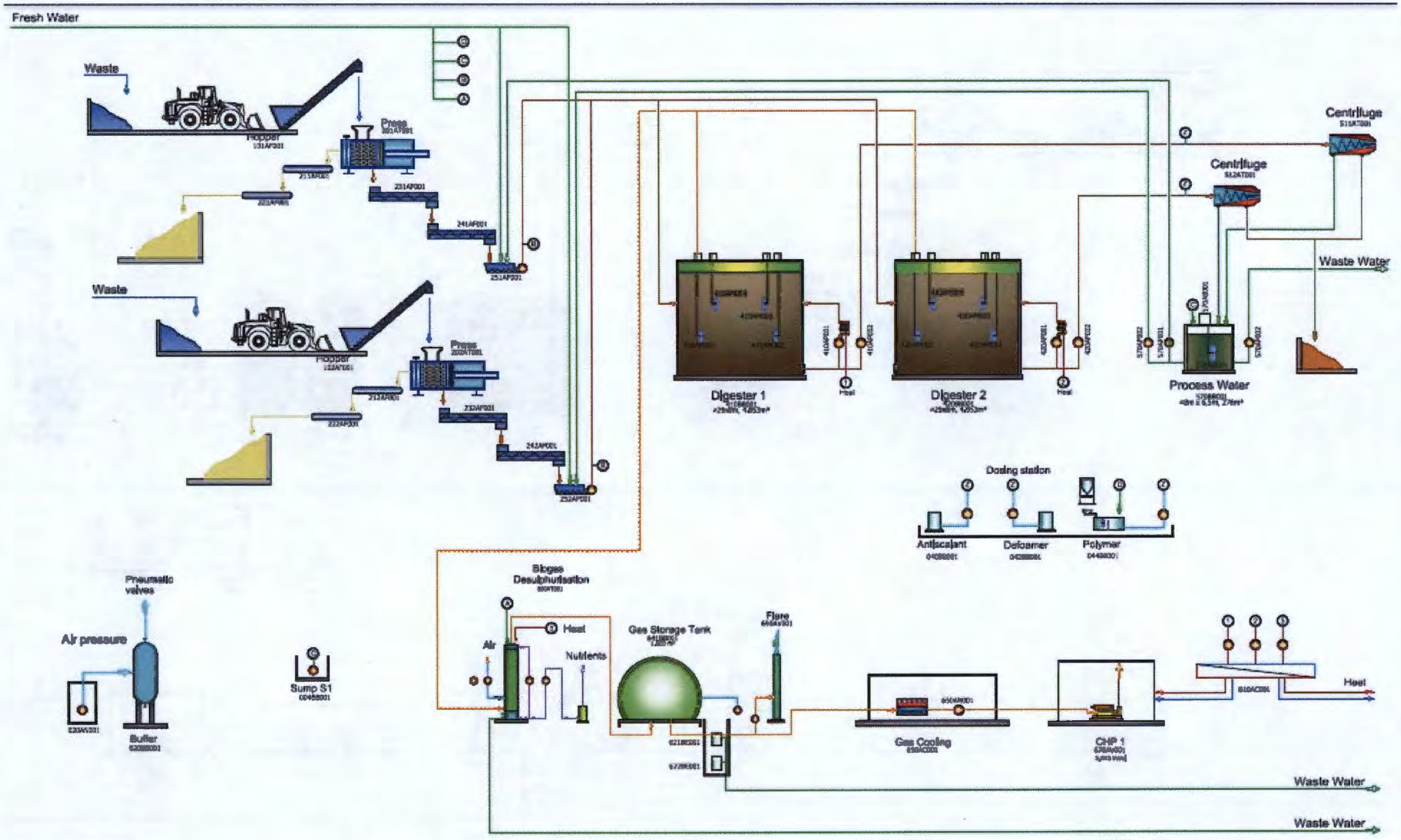
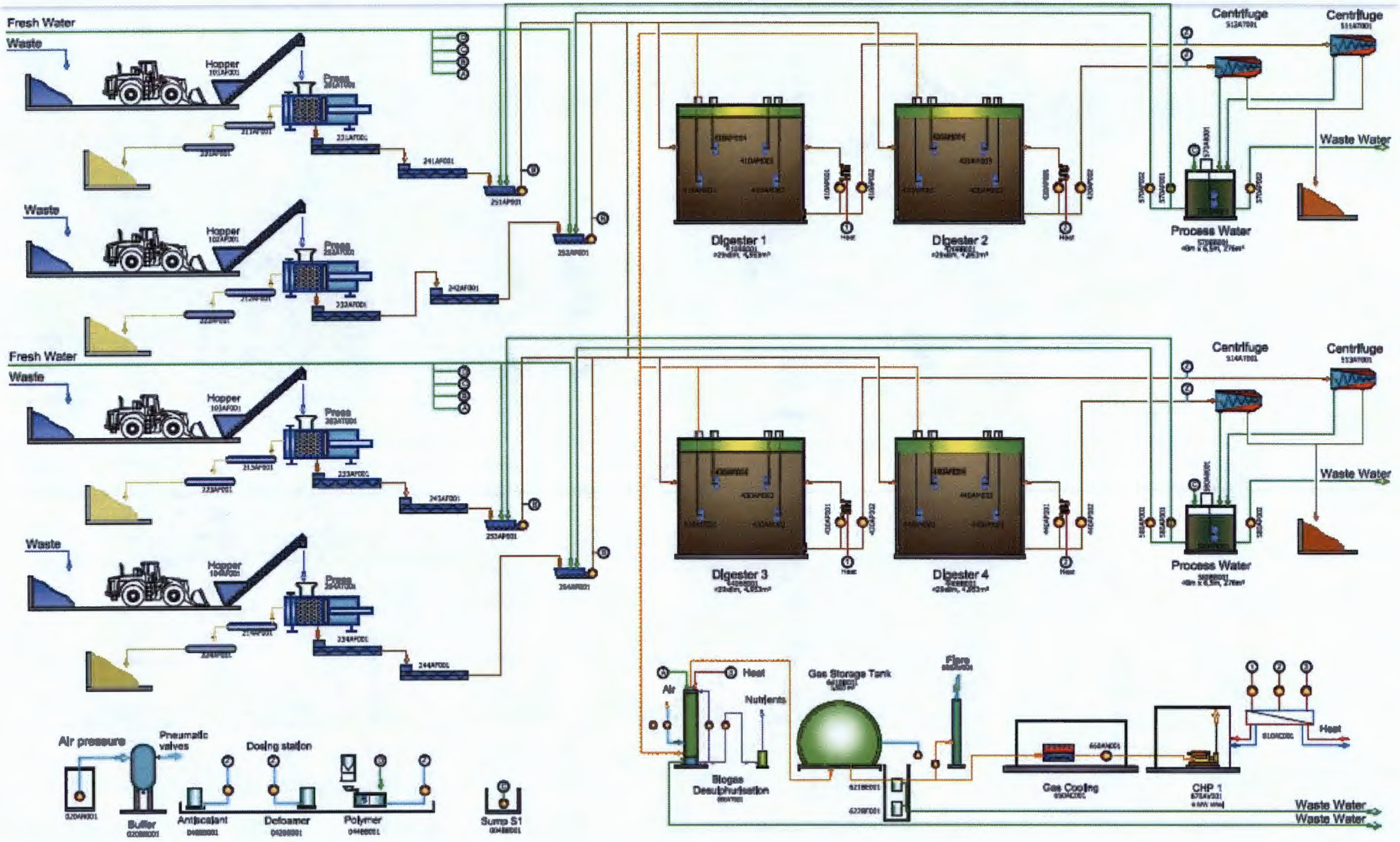
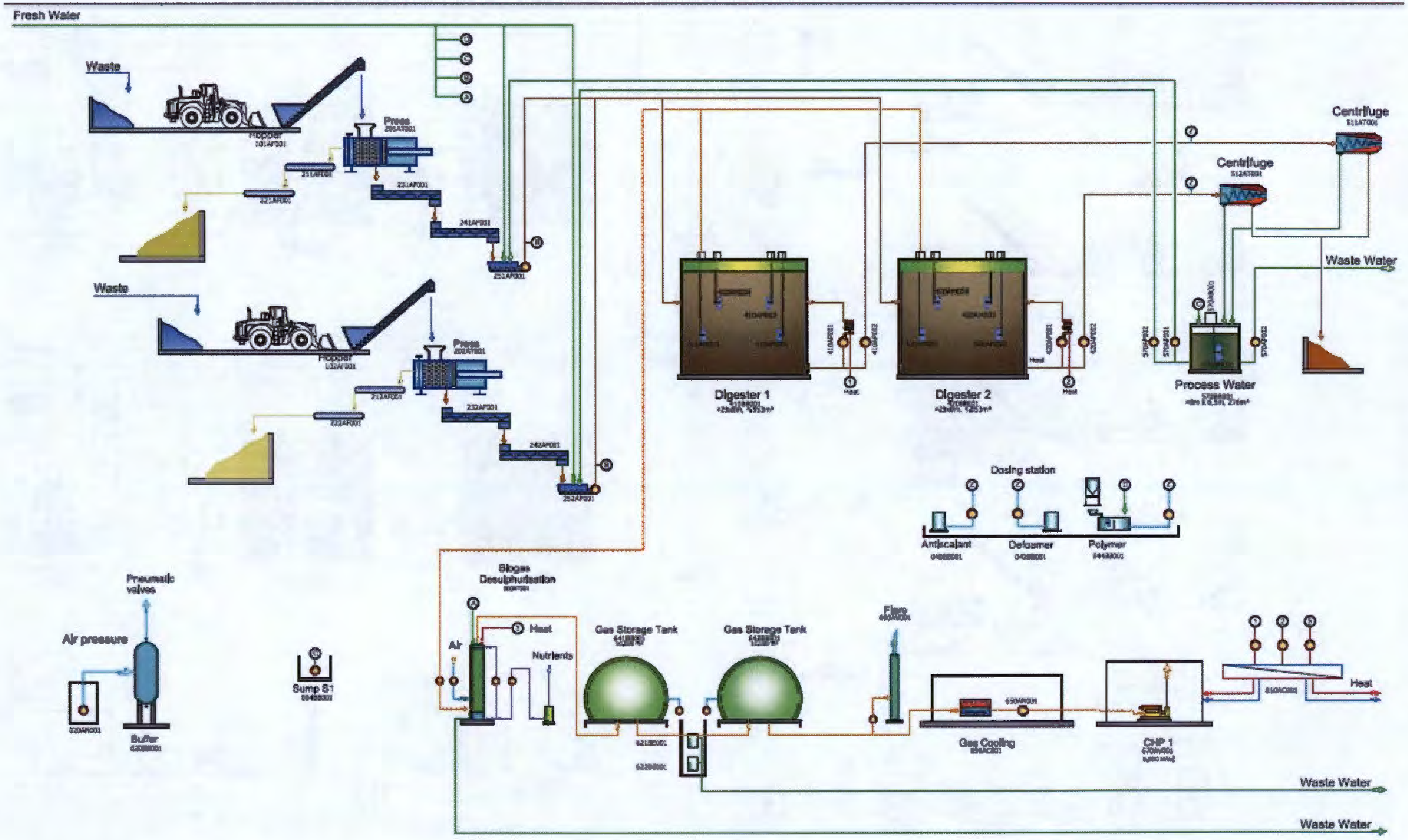

Fresh Water
Waste
Hopper
Press
231AF001
241AF001
251AF001
Waste
Hopper
Press
232AF001
242AF001
252AF001
Digester 1
Heat
Digester 2
Heat
Centrifuge
Centrifuge
Waste Water
Process Water
Dosing station
Antiscalant
Defoamer
Polymer
Pneumatic valves
Air pressure
Buffer
Sump S1
Biogas Desulphurisation
Air
Heat
Nutrients
Gas Storage Tank
Flare
Gas Cooling
CHP 1
Heat
Waste Water
Waste Water

5MW (C)


Fresh Water
Waste
Hopper
Press
Waste
Hopper
Press
Fresh Water
Waste
Hopper
Press
Waste
Hopper
Press
Digester 1
Digester 2
Digester 3
Digester 4
Heat
Heat
Heat
Heat
Centrifuge
Centrifuge
Centrifuge
Centrifuge
Process Water
Process Water
Waste Water
Waste Water
Air pressure
Pneumatic valves
Buffer
Dosing station
Antiscalant
Defoamer
Polymer
Sump S1
Air
Heat
Nutrients
Biogas Desulphurisation
Gas Storage Tank
Flare
Gas Cooling
CHP 1
Heat
Waste Water
Waste Water

5MW (P & S)


Fresh Water
Waste
Hopper
101AF001
Press
201AT001
211AF001
221AF001
231AF001
241AF001
251AF001
Waste
Hopper
102AF001
Press
202AT001
212AF001
222AF001
232AF001
242AF001
252AF001
Digester 1
Digester 2
410AP001
410AP002
420AP001
420AP002
Heat
Heat
Centrifuge
511AT001
Centrifuge
512AT001
570AP001
570AP002
570AP002
Process Water
Waste Water
Dosing station
Antiscalant
Defoamer
Polymer
Pneumatic valves
Air pressure
020AN001
Buffer
Sump S1
Biogas Desulphurisation
Air
Heat
Nutrients
Gas Storage Tank
Gas Storage Tank
Flare
Gas Cooling
650AP001
CHP 1
810AC001
Heat
Waste Water
Waste Water

- The biogas plant will not require authorisation in terms of legislation governing air quality, however an amendment may be required to the Foundry's current Air Emissions Licence. The need for the amendment, and the process for such amendment (if required) can only be confirmed by authorities subsequent to their further investigation of the matter;
- In addition to the Scoping and EIA process that must be undertaken by an independent Environmental Assessment Practitioner (Chand), the project consultants will have to apply to the City of Cape Town for a permit to discharge the treated effluent to sewer.

WAY FORWARD:

The next phase of the project would entail commencing of the Scoping and EIA process in accordance with the 2014 EIA Regulations. A broad overview of the steps in the process is provided below:

- Collation of the relevant project information, the legislative context and baseline environment in order to scope out insignificant environmental issues and determine the issues of significance to assess during the EIA process. This will be documented in the draft Scoping Report (SR) and plan of study for the EIA and will need to be informed by relevant professionals on the project team (e.g. engineers) as well as the following specialist studies:
  - Risk assessment, to determine whether the site must be registered as a Major Hazard Installation (MHI);
  - Heritage and archaeological assessments to inform a Notification of Intent to Develop to Heritage Western Cape.

  No further specialist inputs are identified at this point, however it must be noted that additional inputs may be required depending on the nature of issues raised during the process and/or on request from the authorities.
- Notifying potential Interested and Affected Parties and relevant state departments of the project and distributing the draft SR to these parties in order to obtain comment. The comment received will be taken into account and responded to in the generation of the final SR.
- Submission of the formal applications to the relevant authorities and subsequent public review of the final Scoping Report.
- The authorities will consider the SR and plan of study for EIA, and issue a decision on the Scoping phase of the process. If accepted, the EIA phase may be commenced.
- An assessment of the impacts of significant issues will be undertaken and documented in an Environmental Impact Report (EIR) and a

related Environmental Management Programme (EMPr) will be developed. The EIR and EMPr will be made available for public review. Depending on the nature of comments received during this review period, there may be a need to revise the documentation and conduct a second review of the EIR and EMPr.

- Subsequent to the finalization of the documentation and public review period(s), the final submission will be made to the authorities for their decision-making.

The Scoping and EIA process will take approximately 12-13 months to complete, noting that additional 50 days would be required if a revised EIR and EMPr is necessitated during in the EIA phase. The application for the permit to discharge to sewer can be lodged with the City during the above-mentioned timeframe, however it is likely that the permit will only be issued during the commissioning of the facility.

Authorities indicated that whilst there are limited opportunities to accelerate their decision-making process, renewable energy projects and projects within development priority zones such as Atlantis are prioritized as authorities are required to report to the provincial government on the progress of such applications. It is therefore very likely that the above-mentioned timeframes will be met, provided that the necessary project information is available at the time when the process is commenced.

It is important to note that cost and timing implications of the process to amend the Foundry's existing Air Emission Licence (if required) can only be determined upon the receipt of feedback from the authorities in this regard.

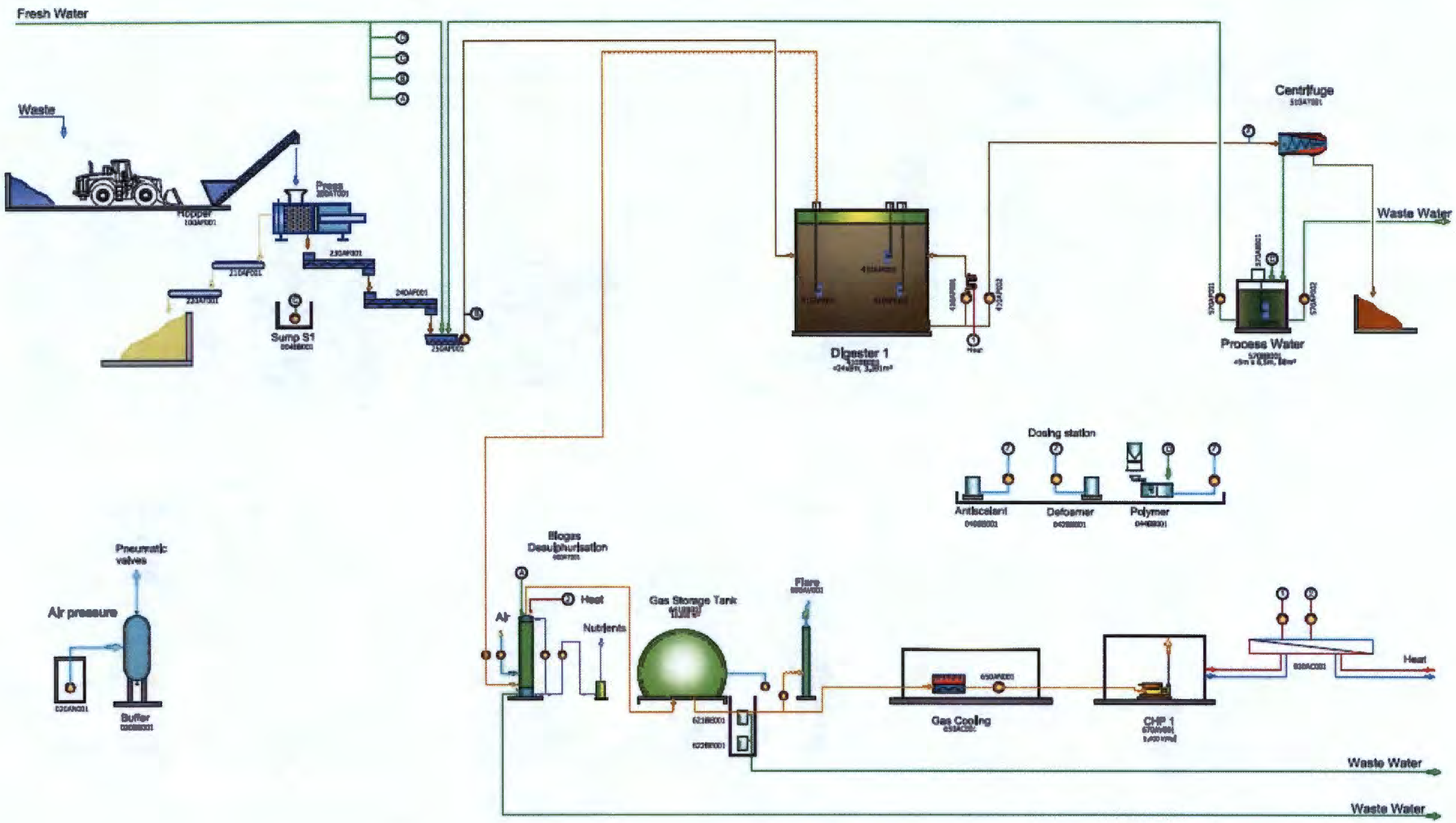
Kind regards

Eggert

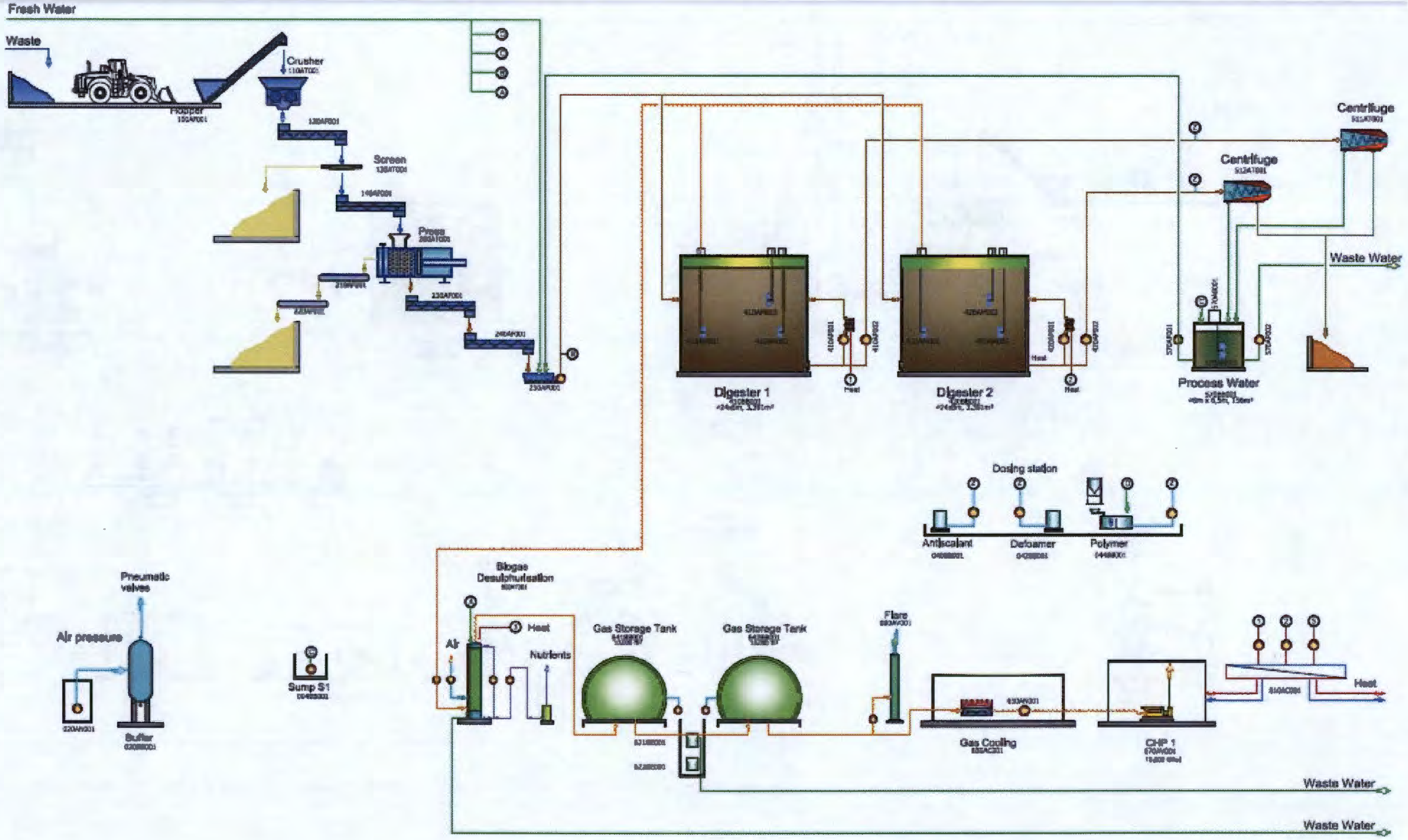
Ingrid Eggert

CHAND ENVIRONMENTAL CONSULTANTS

5MW (P)

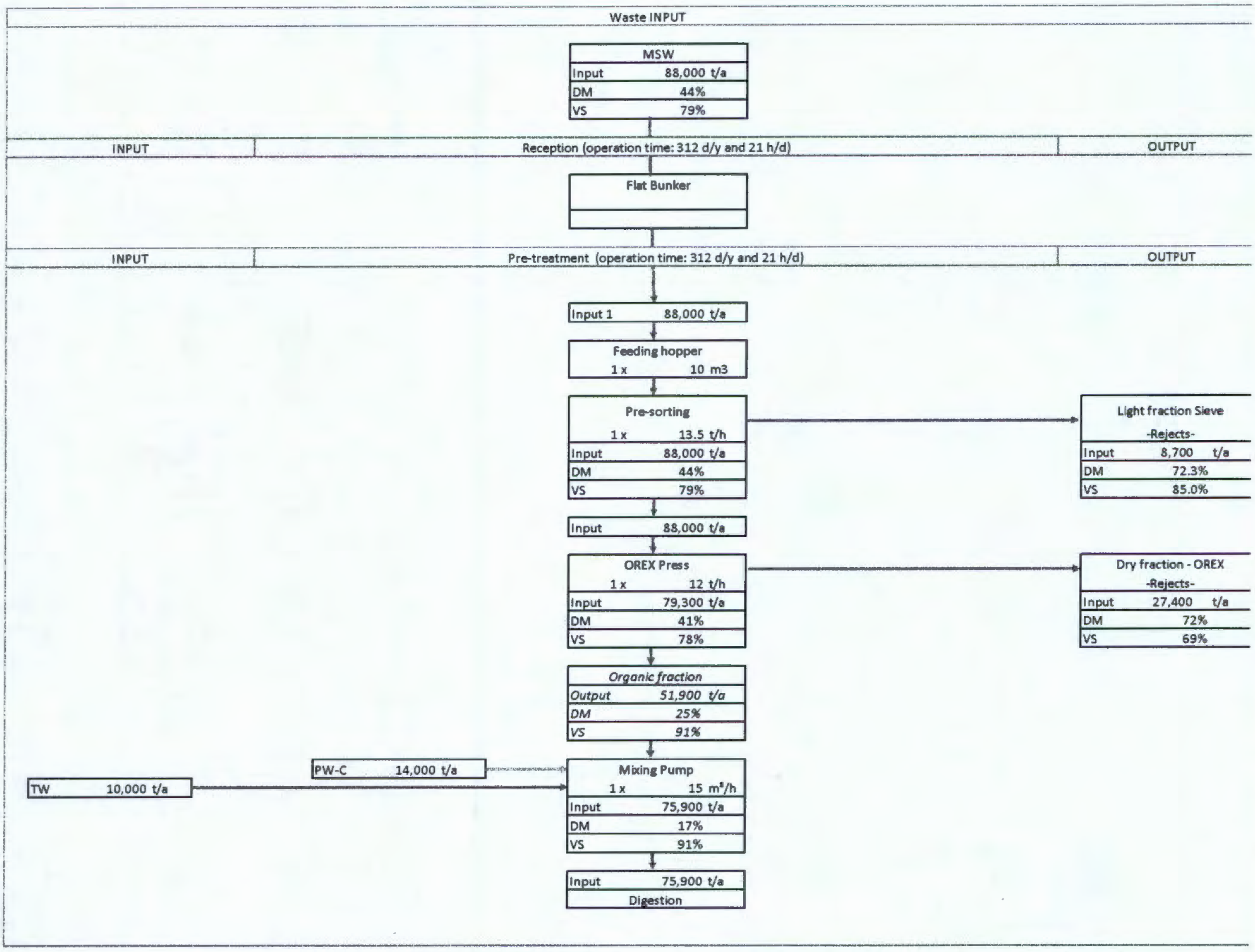

Fresh Water
Waste
Hopper
Press
210AP001
220AP001
230AP001
240AP001
250AP001
Sump S1
Digester 1
430AP001
430AP002
Heat
Centrifuge
Waste Water
570AP001
570AB001
570AP002
Process Water
Dosing station
Antiscalant
Defoamer
Polymer
Air pressure
Pneumatic valves
Buffer
Biogas Desulphurisation
Air
Heat
Nutrients
Gas Storage Tank
Flare
Gas Cooling
650AP001
CHP 1
Heat
Waste Water
Waste Water

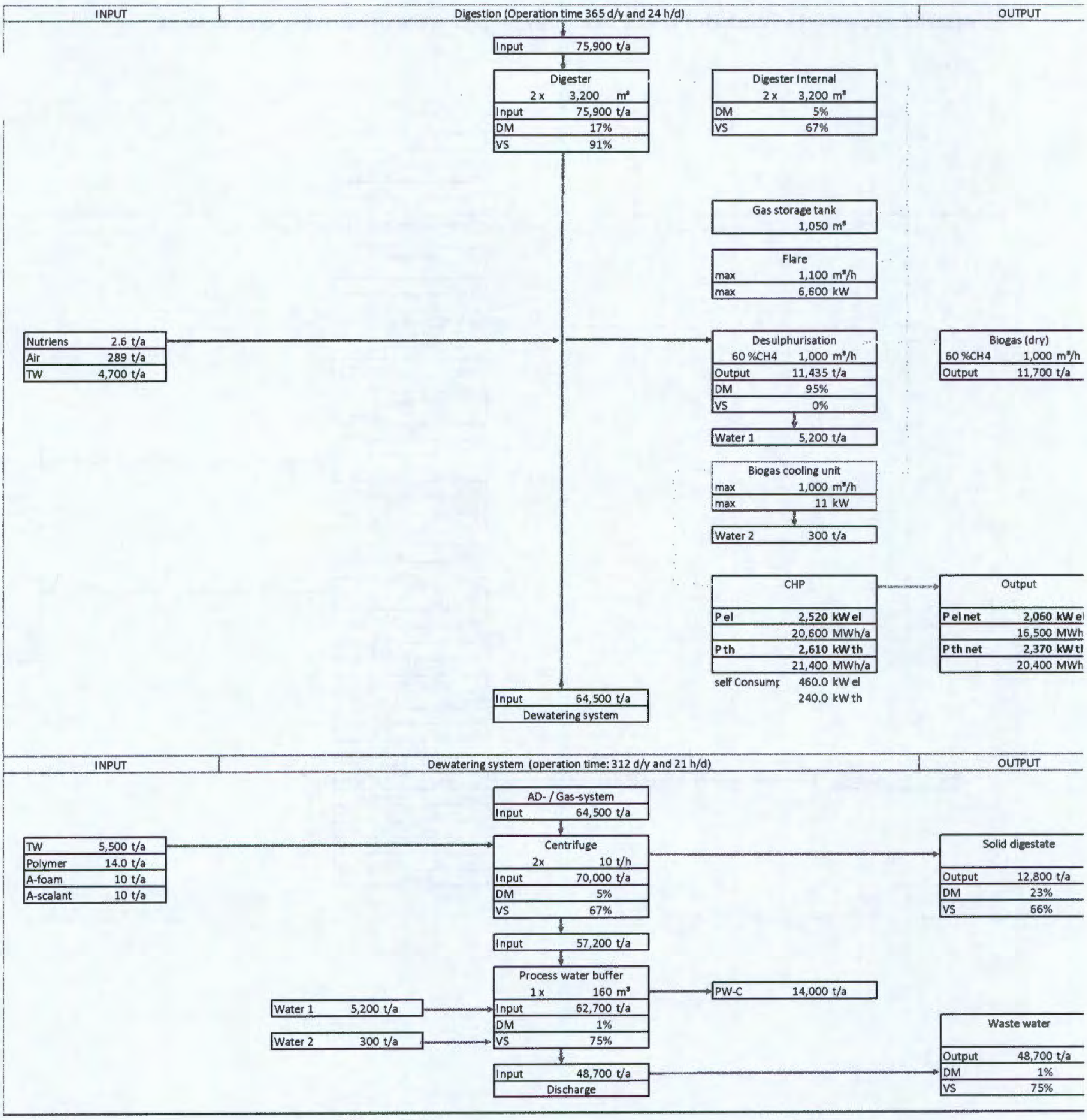
10MW (P)


Fresh Water
Waste
Hopper
Crusher
Screen
Press
Digester 1
Heat
Digester 2
Heat
Centrifuge
Centrifuge
Waste Water
Process Water
Dosing station
Antiscalant
Defoamer
Polymer
Pneumatic valves
Air pressure
Buffer
Sump S1
Biogas Desulphurisation
Heat
Air
Nutrients
Gas Storage Tank
Gas Storage Tank
Flare
Gas Cooling
CHP 1
Heat
Waste Water
Waste Water

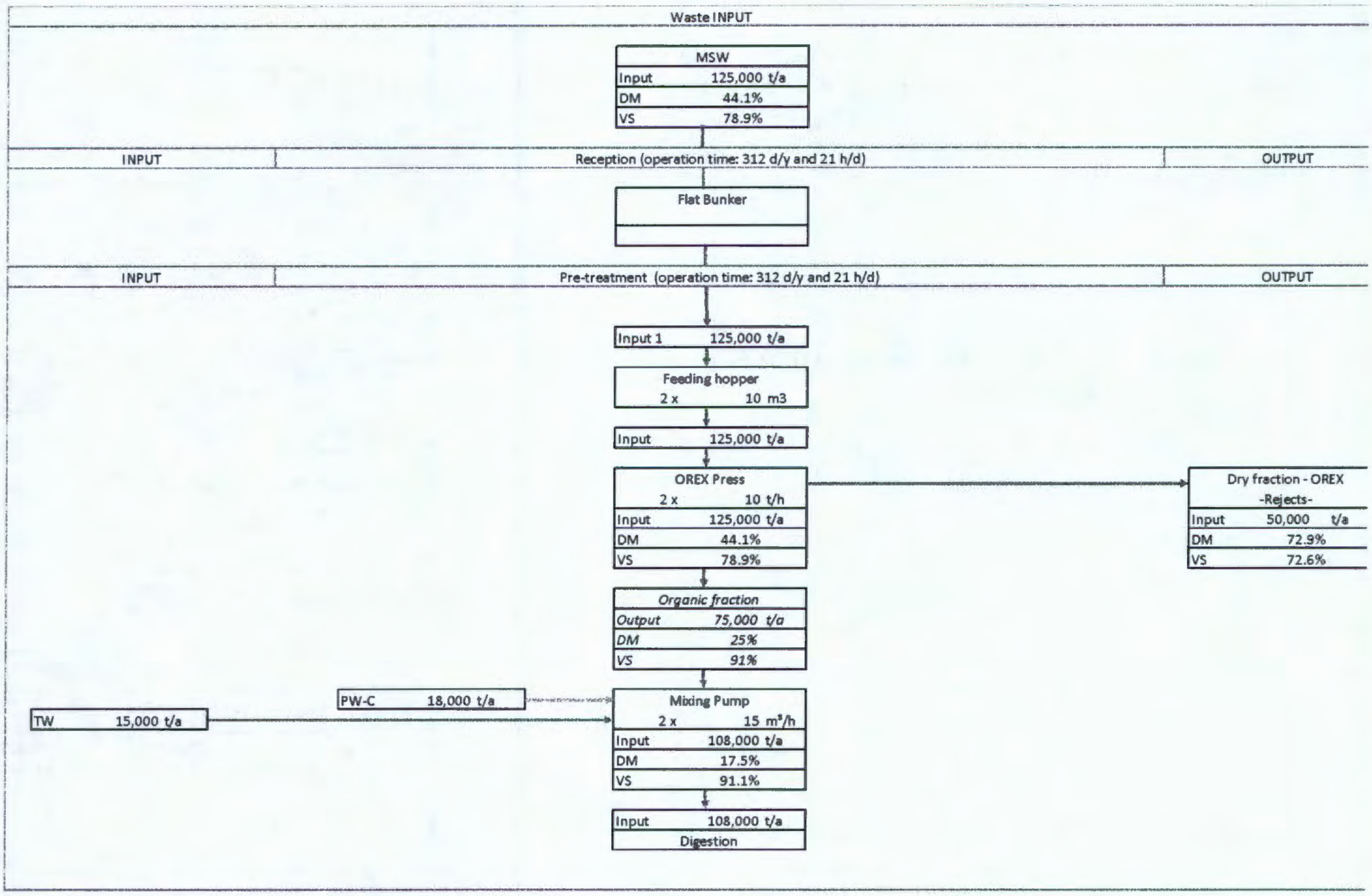
Appendix 5: Atlantis Foundries waste to energy project scenarios mass energy balance

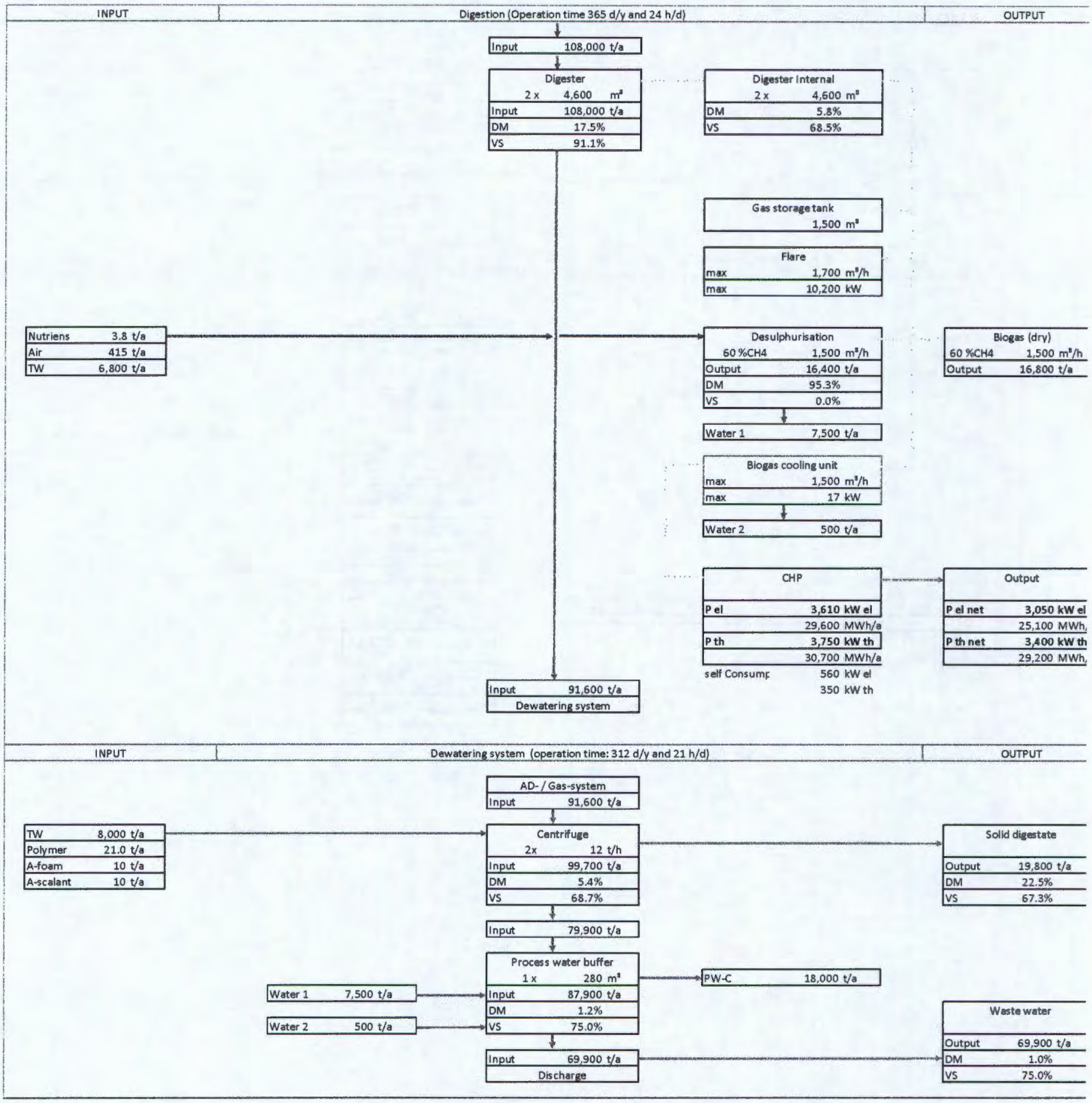
2MW



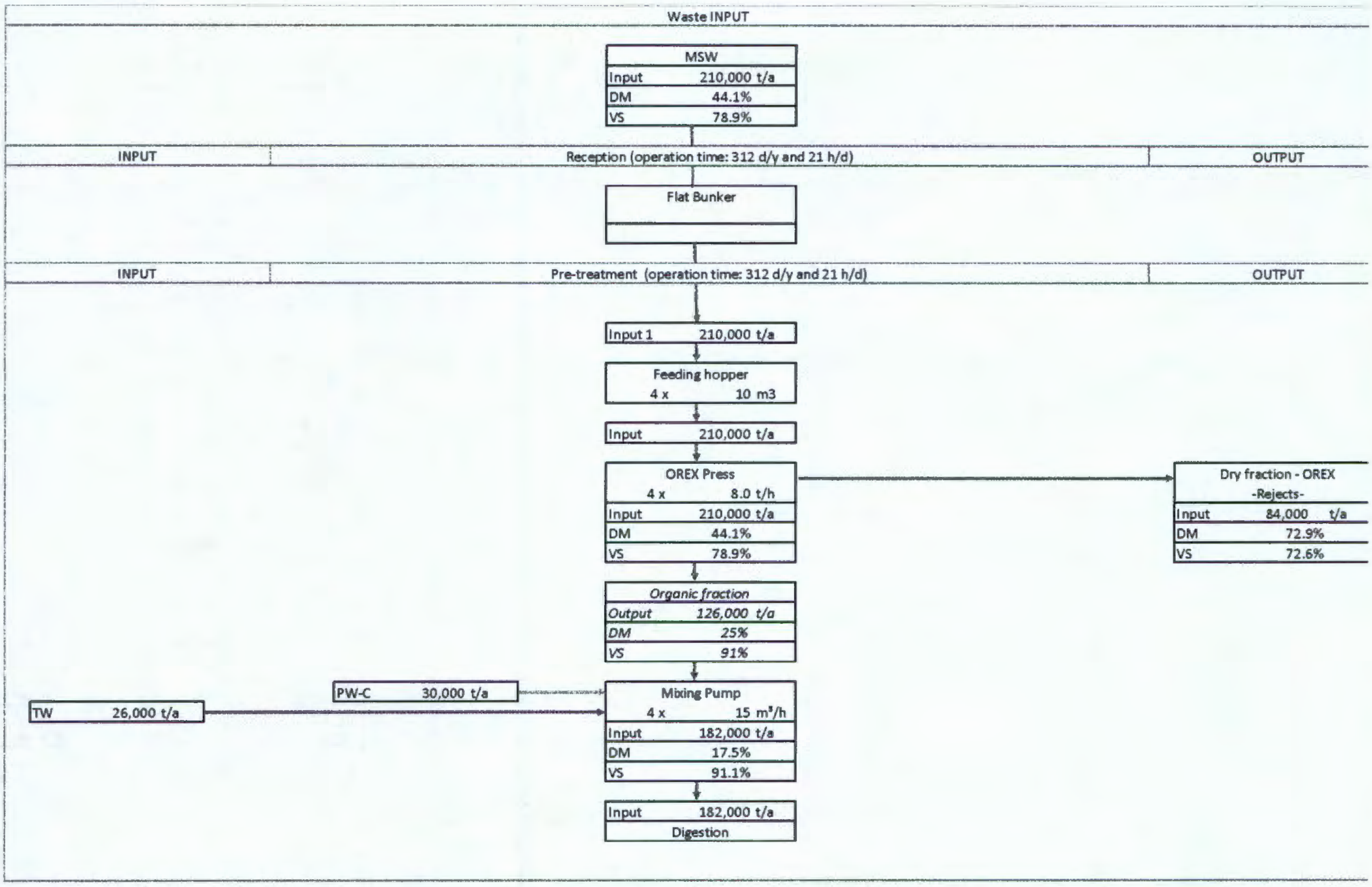

INPUT
Digestion (Operation time 365 d/y and 24 h/d)
OUTPUT
Input 75,900 t/a
Digester
2 x 3,200 m³
Input 75,900 t/a
DM 17%
VS 91%
Digester Internal
2 x 3,200 m³
DM 5%
VS 67%
Gas storage tank
1,050 m³
Flare
max 1,100 m³/h
max 6,600 kW
Nutriens 2.6 t/a
Air 289 t/a
TW 4,700 t/a
Desulphurisation
60 %CH4 1,000 m³/h
Output 11,435 t/a
DM 95%
VS 0%
Water 1 5,200 t/a
Biogas (dry)
60 %CH4 1,000 m³/h
Output 11,700 t/a
Biogas cooling unit
max 1,000 m³/h
max 11 kW
Water 2 300 t/a
CHP
P el 2,520 kW el
20,600 MWh/a
P th 2,610 kW th
21,400 MWh/a
self Consump 460.0 kW el
240.0 kW th
Output
P el net 2,060 kW el
16,500 MWh
P th net 2,370 kW th
20,400 MWh
Input 64,500 t/a
Dewatering system
INPUT
Dewatering system (operation time: 312 d/y and 21 h/d)
OUTPUT
AD- / Gas-system
Input 64,500 t/a
TW 5,500 t/a
Polymer 14.0 t/a
A-foam 10 t/a
A-scalant 10 t/a
Centrifuge
2x 10 t/h
Input 70,000 t/a
DM 5%
VS 67%
Solid digestate
Output 12,800 t/a
DM 23%
VS 66%
Input 57,200 t/a
Process water buffer
1 x 160 m³
Input 62,700 t/a
DM 1%
VS 75%
PW-C 14,000 t/a
Water 1 5,200 t/a
Water 2 300 t/a
Waste water
Output 48,700 t/a
DM 1%
VS 75%
Input 48,700 t/a
Discharge

3MW

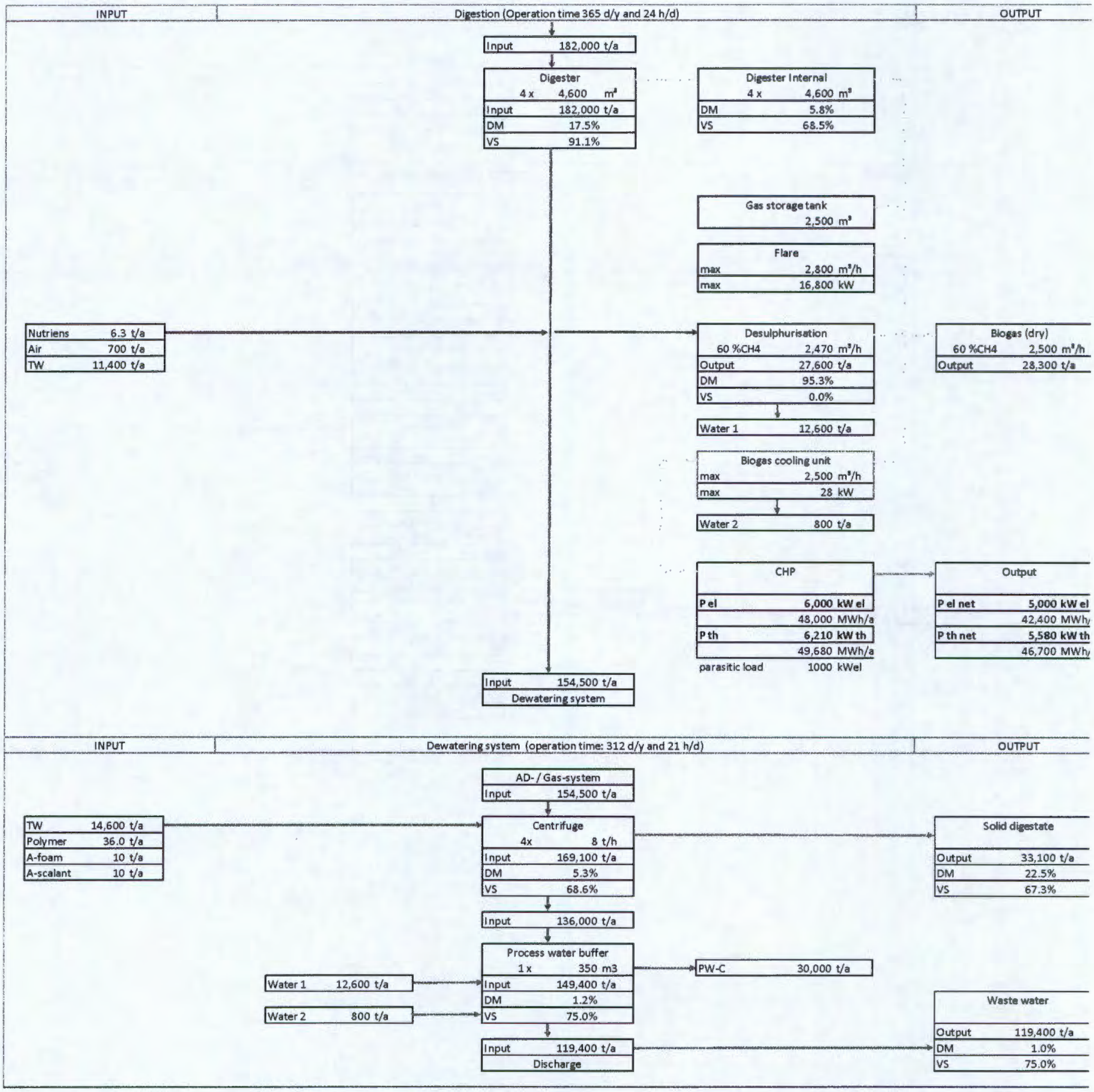

Waste INPUT
MSW
Input 125,000 t/a
DM 44.1%
VS 78.9%
INPUT
Reception (operation time: 312 d/y and 21 h/d)
OUTPUT
Flat Bunker
INPUT
Pre-treatment (operation time: 312 d/y and 21 h/d)
OUTPUT
Input 1 125,000 t/a
Feeding hopper
2 x 10 m3
Input 125,000 t/a
OREX Press
2 x 10 t/h
Input 125,000 t/a
DM 44.1%
VS 78.9%
Dry fraction - OREX
-Rejects-
Input 50,000 t/a
DM 72.9%
VS 72.6%
Organic fraction
Output 75,000 t/a
DM 25%
VS 91%
PW-C 18,000 t/a
TW 15,000 t/a
Mixing Pump
2 x 15 m³/h
Input 108,000 t/a
DM 17.5%
VS 91.1%
Input 108,000 t/a
Digestion


INPUT
Digestion (Operation time 365 d/y and 24 h/d)
OUTPUT
Input 108,000 t/a
Digester
2 x 4,600 m³
Input 108,000 t/a
DM 17.5%
VS 91.1%
Digester Internal
2 x 4,600 m³
DM 5.8%
VS 68.5%
Gas storage tank
1,500 m³
Flare
max 1,700 m³/h
max 10,200 kW
Nutriens 3.8 t/a
Air 415 t/a
TW 6,800 t/a
Desulphurisation
60 %CH4 1,500 m³/h
Output 16,400 t/a
DM 95.3%
VS 0.0%
Biogas (dry)
60 %CH4 1,500 m³/h
Output 16,800 t/a
Water 1 7,500 t/a
Biogas cooling unit
max 1,500 m³/h
max 17 kW
Water 2 500 t/a
CHP
P el 3,610 kW el
29,600 MWh/a
P th 3,750 kW th
30,700 MWh/a
self Consump 560 kW el
350 kW th
Output
P el net 3,050 kW el
25,100 MWh,
P th net 3,400 kW th
29,200 MWh,
Input 91,600 t/a
Dewatering system
INPUT
Dewatering system (operation time: 312 d/y and 21 h/d)
OUTPUT
AD- / Gas-system
Input 91,600 t/a
TW 8,000 t/a
Polymer 21.0 t/a
A-foam 10 t/a
A-scalant 10 t/a
Centrifuge
2x 12 t/h
Input 99,700 t/a
DM 5.4%
VS 68.7%
Solid digestate
Output 19,800 t/a
DM 22.5%
VS 67.3%
Input 79,900 t/a
Process water buffer
1 x 280 m³
Input 87,900 t/a
DM 1.2%
VS 75.0%
PW-C 18,000 t/a
Water 1 7,500 t/a
Water 2 500 t/a
Waste water
Output 69,900 t/a
DM 1.0%
VS 75.0%
Input 69,900 t/a
Discharge

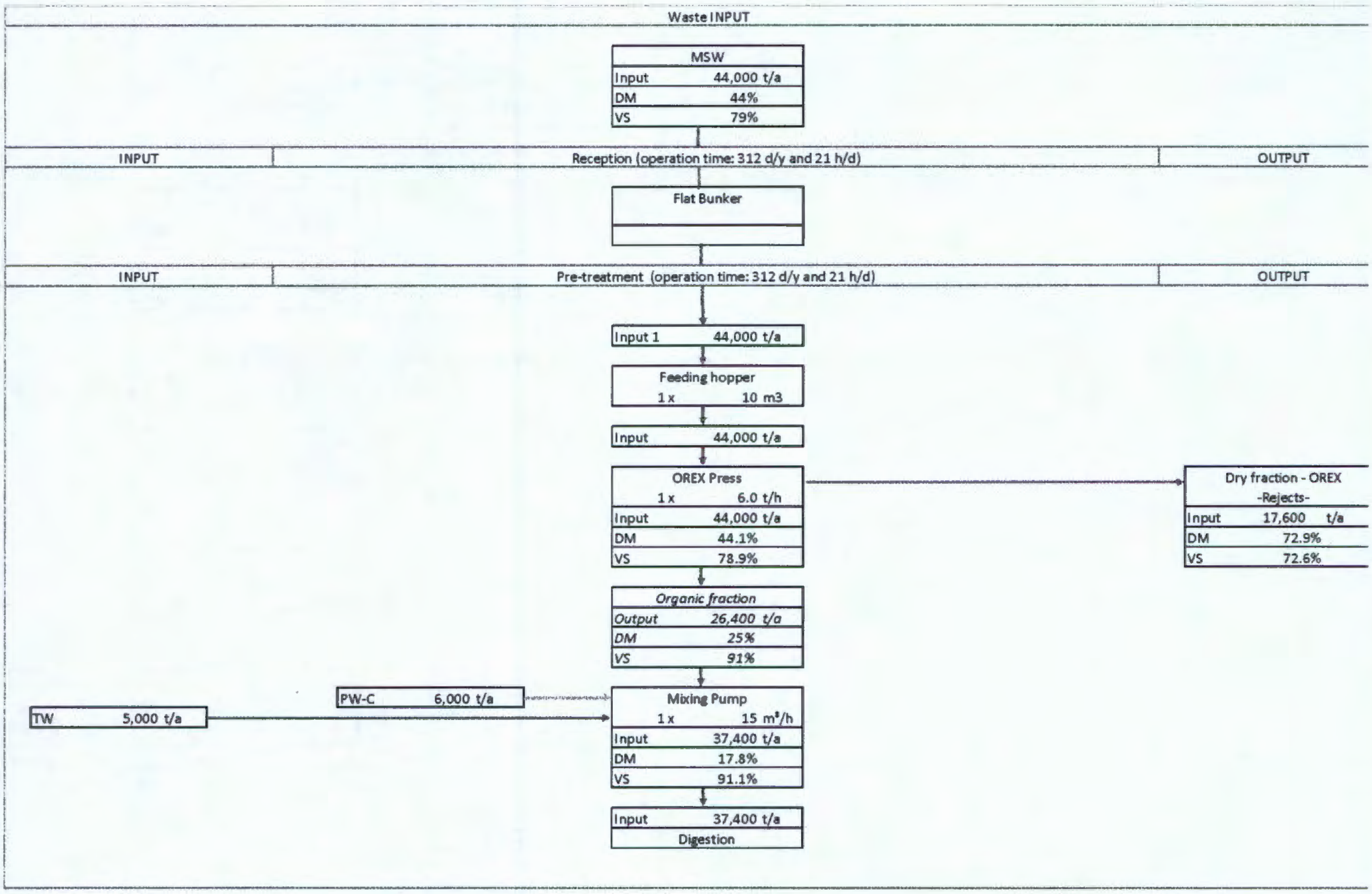
5MW (c)

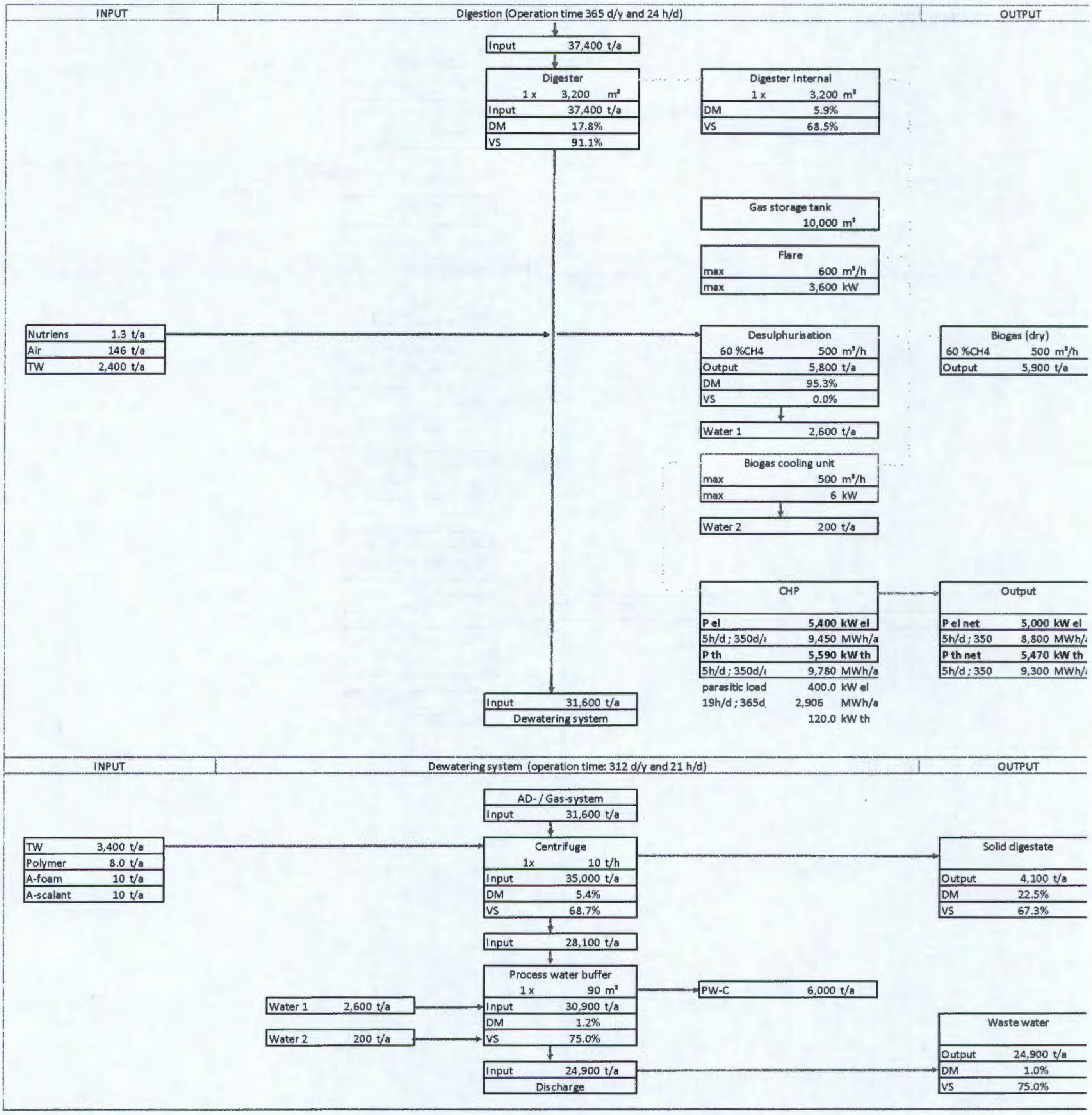


Waste INPUT
MSW
Input 210,000 t/a
DM 44.1%
VS 78.9%
INPUT
Reception (operation time: 312 d/y and 21 h/d)
OUTPUT
Flat Bunker
INPUT
Pre-treatment (operation time: 312 d/y and 21 h/d)
OUTPUT
Input 1 210,000 t/a
Feeding hopper
4 x 10 m3
Input 210,000 t/a
OREX Press
4 x 8.0 t/h
Input 210,000 t/a
DM 44.1%
VS 78.9%
Dry fraction - OREX
-Rejects-
Input 84,000 t/a
DM 72.9%
VS 72.6%
Organic fraction
Output 126,000 t/a
DM 25%
VS 91%
PW-C 30,000 t/a
TW 26,000 t/a
Mixing Pump
4 x 15 m³/h
Input 182,000 t/a
DM 17.5%
VS 91.1%
Input 182,000 t/a
Digestion

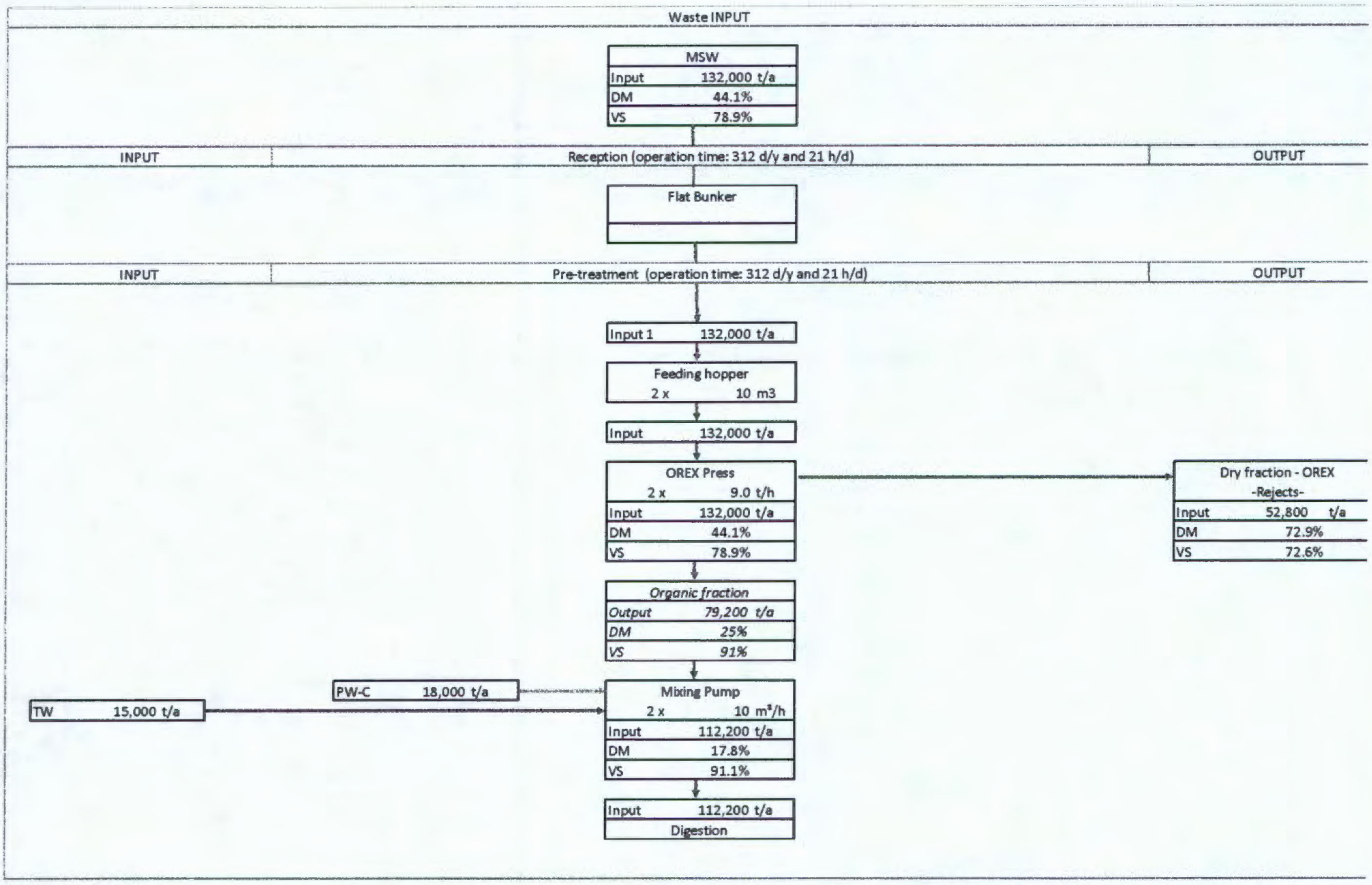

INPUT
Digestion (Operation time 365 d/y and 24 h/d)
OUTPUT
Input 182,000 t/a
Digester
4 x 4,600 m³
Input 182,000 t/a
DM 17.5%
VS 91.1%
Digester Internal
4 x 4,600 m³
DM 5.8%
VS 68.5%
Gas storage tank
2,500 m³
Flare
max 2,800 m³/h
max 16,800 kW
Nutriens 6.3 t/a
Air 700 t/a
TW 11,400 t/a
Desulphurisation
60 %CH4 2,470 m³/h
Output 27,600 t/a
DM 95.3%
VS 0.0%
Biogas (dry)
60 %CH4 2,500 m³/h
Output 28,300 t/a
Water 1 12,600 t/a
Biogas cooling unit
max 2,500 m³/h
max 28 kW
Water 2 800 t/a
CHP
P el 6,000 kW el
48,000 MWh/a
P th 6,210 kW th
49,680 MWh/a
parasitic load 1000 kWel
Output
P el net 5,000 kW el
42,400 MWh
P th net 5,580 kW th
46,700 MWh
Input 154,500 t/a
Dewatering system
INPUT
Dewatering system (operation time: 312 d/y and 21 h/d)
OUTPUT
AD- / Gas-system
Input 154,500 t/a
TW 14,600 t/a
Polymer 36.0 t/a
A-foam 10 t/a
A-scalant 10 t/a
Centrifuge
4x 8 t/h
Input 169,100 t/a
DM 5.3%
VS 68.6%
Solid digestate
Output 33,100 t/a
DM 22.5%
VS 67.3%
Input 136,000 t/a
Process water buffer
1 x 350 m3
Input 149,400 t/a
DM 1.2%
VS 75.0%
PW-C 30,000 t/a
Water 1 12,600 t/a
Water 2 800 t/a
Waste water
Output 119,400 t/a
DM 1.0%
VS 75.0%
Input 119,400 t/a
Discharge

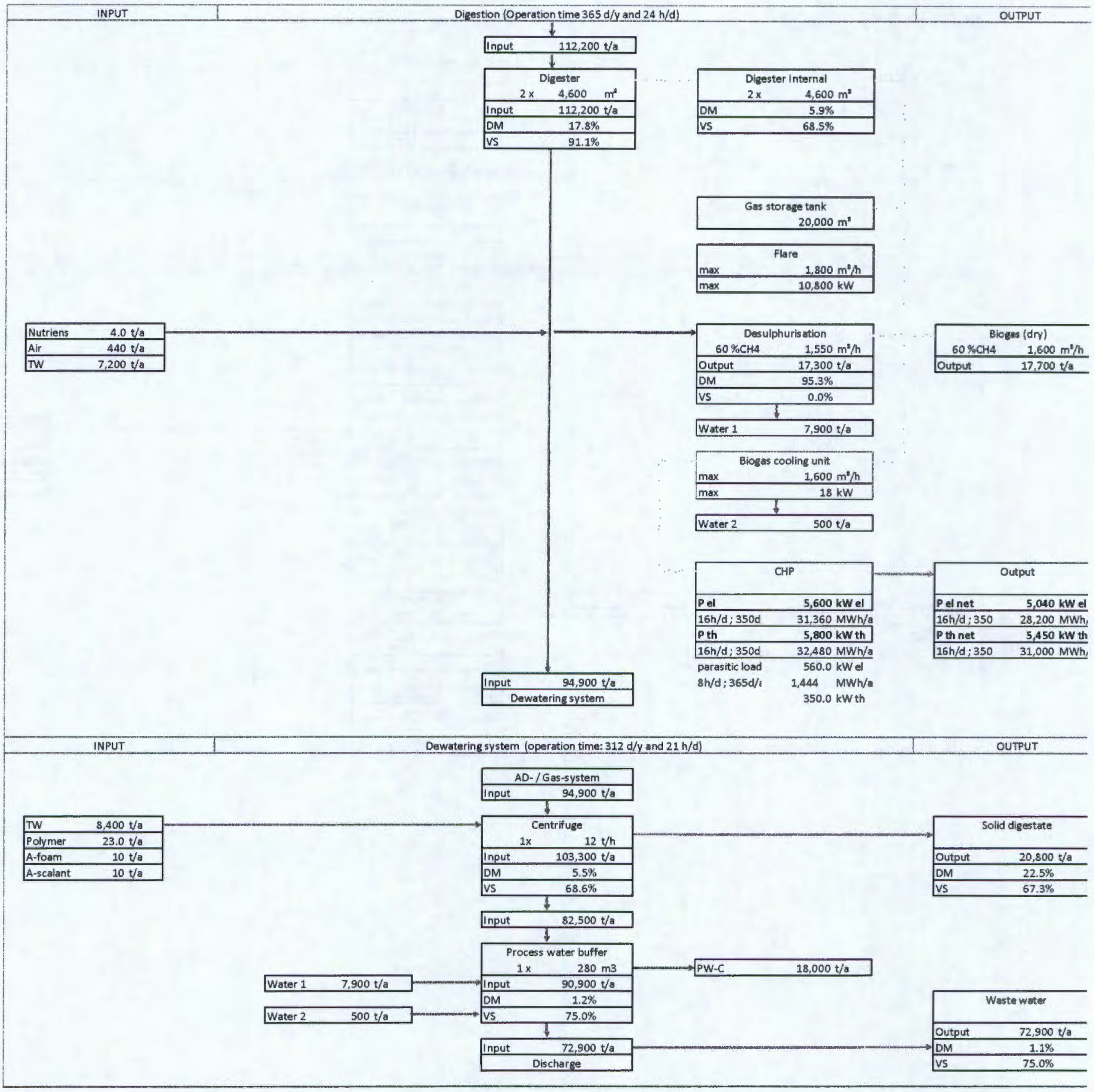
5MW (P)


Waste INPUT
MSW
Input 44,000 t/a
DM 44%
VS 79%
INPUT
Reception (operation time: 312 d/y and 21 h/d)
OUTPUT
Flat Bunker
INPUT
Pre-treatment (operation time: 312 d/y and 21 h/d)
OUTPUT
Input 1 44,000 t/a
Feeding hopper
1 x 10 m3
Input 44,000 t/a
OREX Press
1 x 6.0 t/h
Input 44,000 t/a
DM 44.1%
VS 78.9%
Dry fraction - OREX
-Rejects-
Input 17,600 t/a
DM 72.9%
VS 72.6%
Organic fraction
Output 26,400 t/a
DM 25%
VS 91%
TW 5,000 t/a
PW-C 6,000 t/a
Mixing Pump
1 x 15 m³/h
Input 37,400 t/a
DM 17.8%
VS 91.1%
Input 37,400 t/a
Digestion

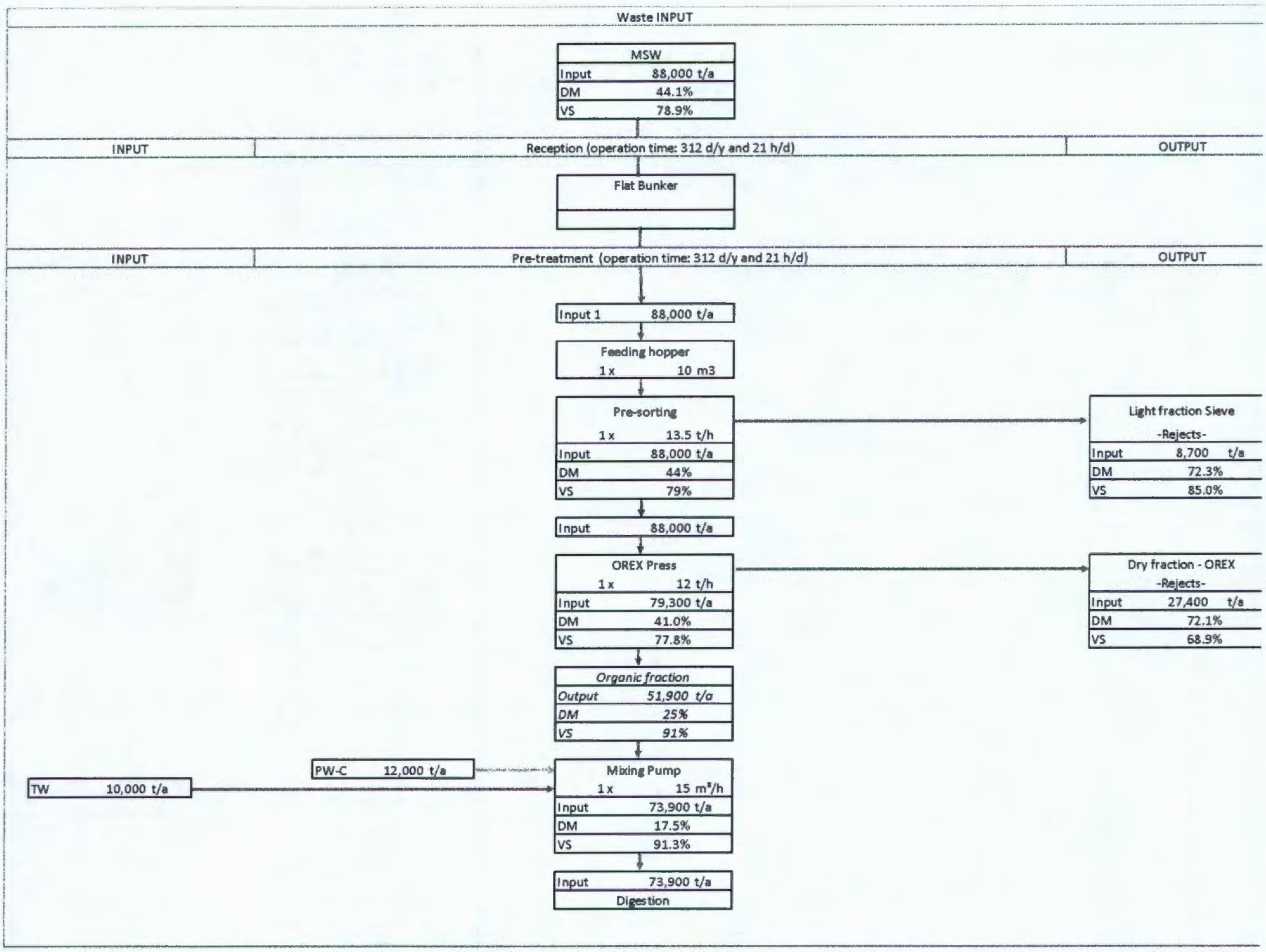

INPUT
Digestion (Operation time 365 d/y and 24 h/d)
OUTPUT
Input 37,400 t/a
Digester
1 x 3,200 m³
Input 37,400 t/a
DM 17.8%
VS 91.1%
Digester Internal
1 x 3,200 m³
DM 5.9%
VS 68.5%
Gas storage tank
10,000 m³
Flare
max 600 m³/h
max 3,600 kW
Nutriens 1.3 t/a
Air 146 t/a
TW 2,400 t/a
Desulphurisation
60 %CH4 500 m³/h
Output 5,800 t/a
DM 95.3%
VS 0.0%
Biogas (dry)
60 %CH4 500 m³/h
Output 5,900 t/a
Water 1 2,600 t/a
Biogas cooling unit
max 500 m³/h
max 6 kW
Water 2 200 t/a
CHP
P el 5,400 kW el
5h/d ; 350d/ 9,450 MWh/a
P th 5,590 kW th
5h/d ; 350d/ 9,780 MWh/a
parasitic load 400.0 kW el
19h/d ; 365d 2,906 MWh/a
120.0 kW th
Output
P el net 5,000 kW el
5h/d ; 350 8,800 MWh/
P th net 5,470 kW th
5h/d ; 350 9,300 MWh/
Input 31,600 t/a
Dewatering system
INPUT
Dewatering system (operation time: 312 d/y and 21 h/d)
OUTPUT
AD- / Gas-system
Input 31,600 t/a
TW 3,400 t/a
Polymer 8.0 t/a
A-foam 10 t/a
A-scalant 10 t/a
Centrifuge
1x 10 t/h
Input 35,000 t/a
DM 5.4%
VS 68.7%
Solid digestate
Output 4,100 t/a
DM 22.5%
VS 67.3%
Input 28,100 t/a
Process water buffer
1 x 90 m³
Input 30,900 t/a
DM 1.2%
VS 75.0%
PW-C 6,000 t/a
Water 1 2,600 t/a
Water 2 200 t/a
Waste water
Output 24,900 t/a
DM 1.0%
VS 75.0%
Input 24,900 t/a
Discharge

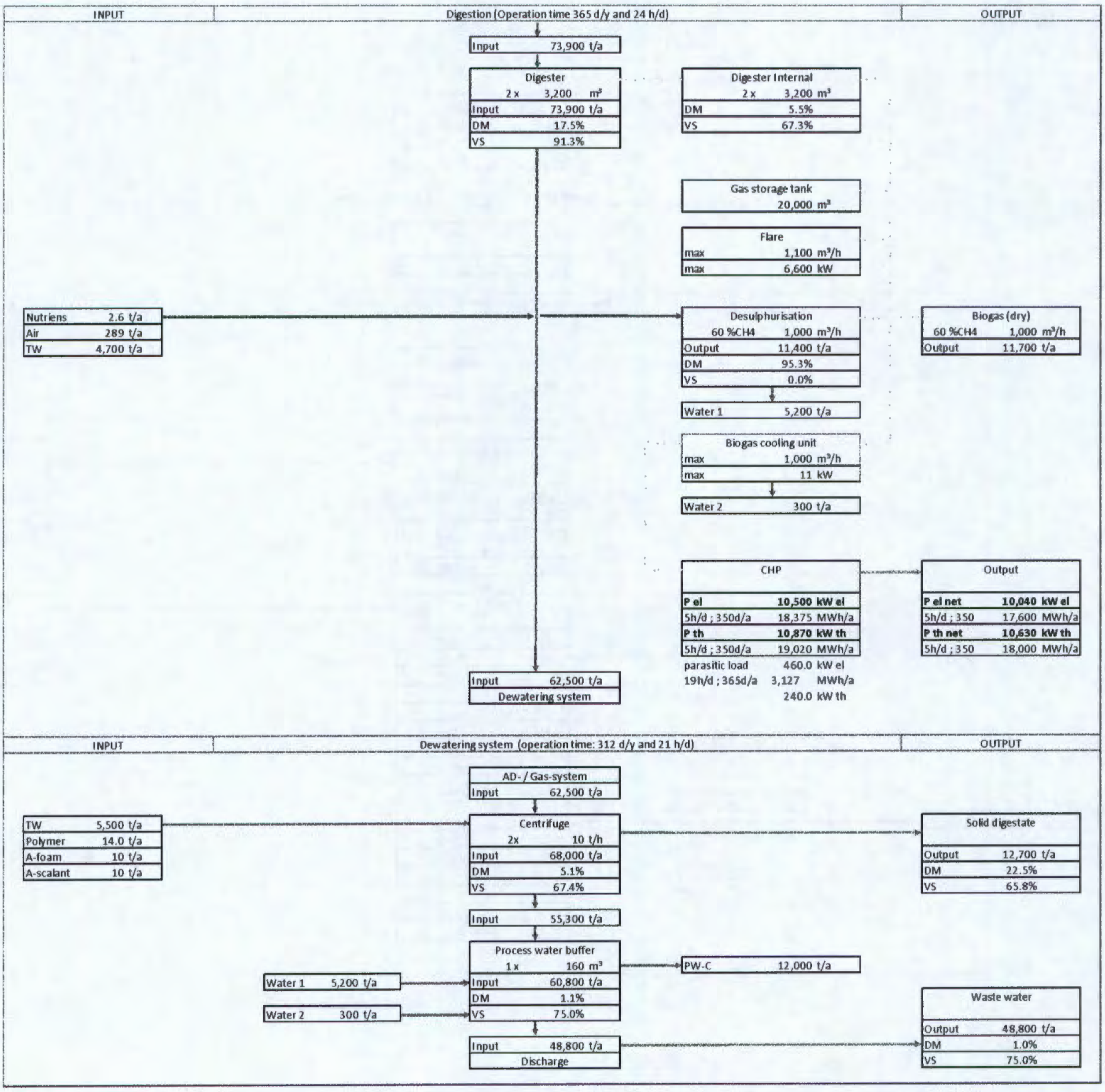
5MW (P & S)


Waste INPUT
MSW
Input 132,000 t/a
DM 44.1%
VS 78.9%
INPUT
Reception (operation time: 312 d/y and 21 h/d)
OUTPUT
Flat Bunker
INPUT
Pre-treatment (operation time: 312 d/y and 21 h/d)
OUTPUT
Input 1 132,000 t/a
Feeding hopper
2 x 10 m3
Input 132,000 t/a
OREX Press
2 x 9.0 t/h
Input 132,000 t/a
DM 44.1%
VS 78.9%
Dry fraction - OREX
-Rejects-
Input 52,800 t/a
DM 72.9%
VS 72.6%
Organic fraction
Output 79,200 t/a
DM 25%
VS 91%
PW-C 18,000 t/a
TW 15,000 t/a
Mixing Pump
2 x 10 m³/h
Input 112,200 t/a
DM 17.8%
VS 91.1%
Input 112,200 t/a
Digestion


INPUT
Digestion (Operation time 365 d/y and 24 h/d)
OUTPUT
Input 112,200 t/a
Digester
2 x 4,600 m^3
Input 112,200 t/a
DM 17.8%
VS 91.1%
Digester Internal
2 x 4,600 m^3
DM 5.9%
VS 68.5%
Gas storage tank
20,000 m^3
Flare
max 1,800 m^3/h
max 10,800 kW
Nutriens 4.0 t/a
Air 440 t/a
TW 7,200 t/a
Desulphurisation
60 %CH4 1,550 m^3/h
Output 17,300 t/a
DM 95.3%
VS 0.0%
Biogas (dry)
60 %CH4 1,600 m^3/h
Output 17,700 t/a
Water 1 7,900 t/a
Biogas cooling unit
max 1,600 m^3/h
max 18 kW
Water 2 500 t/a
CHP
P el 5,600 kW el
16h/d ; 350d 31,360 MWh/a
P th 5,800 kW th
16h/d ; 350d 32,480 MWh/a
parasitic load 560.0 kW el
8h/d ; 365d/ 1,444 MWh/a
350.0 kW th
Output
P el net 5,040 kW el
16h/d ; 350 28,200 MWh/
P th net 5,450 kW th
16h/d ; 350 31,000 MWh/
Input 94,900 t/a
Dewatering system
INPUT
Dewatering system (operation time: 312 d/y and 21 h/d)
OUTPUT
AD- / Gas-system
Input 94,900 t/a
TW 8,400 t/a
Polymer 23.0 t/a
A-foam 10 t/a
A-scalant 10 t/a
Centrifuge
1x 12 t/h
Input 103,300 t/a
DM 5.5%
VS 68.6%
Solid digestate
Output 20,800 t/a
DM 22.5%
VS 67.3%
Input 82,500 t/a
Process water buffer
1 x 280 m3
Input 90,900 t/a
DM 1.2%
VS 75.0%
PW-C 18,000 t/a
Water 1 7,900 t/a
Water 2 500 t/a
Waste water
Output 72,900 t/a
DM 1.1%
VS 75.0%
Input 72,900 t/a
Discharge

10MW (P)


Waste INPUT
MSW
Input 88,000 t/a
DM 44.1%
VS 78.9%
INPUT
Reception (operation time: 312 d/y and 21 h/d)
OUTPUT
Flat Bunker
INPUT
Pre-treatment (operation time: 312 d/y and 21 h/d)
OUTPUT
Input 1 88,000 t/a
Feeding hopper
1 x 10 m3
Pre-sorting
1 x 13.5 t/h
Input 88,000 t/a
DM 44%
VS 79%
Light fraction Sieve
-Rejects-
Input 8,700 t/a
DM 72.3%
VS 85.0%
Input 88,000 t/a
OREX Press
1 x 12 t/h
Input 79,300 t/a
DM 41.0%
VS 77.8%
Dry fraction - OREX
-Rejects-
Input 27,400 t/a
DM 72.1%
VS 68.9%
Organic fraction
Output 51,900 t/a
DM 25%
VS 91%
PW-C 12,000 t/a
TW 10,000 t/a
Mixing Pump
1 x 15 m³/h
Input 73,900 t/a
DM 17.5%
VS 91.3%
Input 73,900 t/a
Digestion


INPUT
Digestion (Operation time 365 d/y and 24 h/d)
OUTPUT
Input 73,900 t/a
Digester
2 x 3,200 m³
Input 73,900 t/a
DM 17.5%
VS 91.3%
Digester Internal
2 x 3,200 m³
DM 5.5%
VS 67.3%
Gas storage tank
20,000 m³
Flare
max 1,100 m³/h
max 6,600 kW
Nutriens 2.6 t/a
Air 289 t/a
TW 4,700 t/a
Desulphurisation
60 %CH4 1,000 m³/h
Output 11,400 t/a
DM 95.3%
VS 0.0%
Biogas (dry)
60 %CH4 1,000 m³/h
Output 11,700 t/a
Water 1 5,200 t/a
Biogas cooling unit
max 1,000 m³/h
max 11 kW
Water 2 300 t/a
CHP
P el 10,500 kW el
5h/d ; 350d/a 18,375 MWh/a
P th 10,870 kW th
5h/d ; 350d/a 19,020 MWh/a
parasitic load 460.0 kW el
19h/d ; 365d/a 3,127 MWh/a
240.0 kW th
Output
P el net 10,040 kW el
5h/d ; 350 17,600 MWh/a
P th net 10,630 kW th
5h/d ; 350 18,000 MWh/a
Input 62,500 t/a
Dewatering system
INPUT
Dewatering system (operation time: 312 d/y and 21 h/d)
OUTPUT
AD- / Gas-system
Input 62,500 t/a
TW 5,500 t/a
Polymer 14.0 t/a
A-foam 10 t/a
A-scalant 10 t/a
Centrifuge
2x 10 t/h
Input 68,000 t/a
DM 5.1%
VS 67.4%
Solid digestate
Output 12,700 t/a
DM 22.5%
VS 65.8%
Input 55,300 t/a
Process water buffer
1 x 160 m³
Input 60,800 t/a
DM 1.1%
VS 75.0%
PW-C 12,000 t/a
Water 1 5,200 t/a
Water 2 300 t/a
Waste water
Output 48,800 t/a
DM 1.0%
VS 75.0%
Input 48,800 t/a
Discharge

Appendix 6: Atlantis Foundries waste to energy project scenarios financial cash flow projection

2MW

Item	Units	Escelation (if not CPI)	Year	0	1	3	5	7	9	11	13	15	20
Inputs and Outputs													
Energy sold (electricty)	KWh/y				16,500,000	16,500,000	16,500,000	16,500,000	16,500,000	16,500,000	16,500,000	16,500,000	16,500,000
Energy sold (heat)	KWh/y				13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000
Waste received	t/y				88,000	88,000	88,000	88,000	88,000	88,000	88,000	88,000	88,000
Electricity used	KWh/y				4,100,000	4,100,000	4,100,000	4,100,000	4,100,000	4,100,000	4,100,000	4,100,000	4,100,000
Fresh water used	m³/y				20,200	20,200	20,200	20,200	20,200	20,200	20,200	20,200	20,200
Liquide effluent	m³/y				48,700	48,700	48,700	48,700	48,700	48,700	48,700	48,700	48,700
Compost	t/y				12,800	12,800	12,800	12,800	12,800	12,800	12,800	12,800	12,800
Waste for dumping	t/y				36,100	36,100	36,100	36,100	36,100	36,100	36,100	36,100	36,100
Nutrients (desulphuriz	t/y				2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Polymer	t/y				14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
A-scalant (polymer)	t/y				10	10	10	10	10	10	10	10	10
A-foam (polymer)	t/y				10	10	10	10	10	10	10	10	10
Variable Rates													
Energy selling price (el	R/KWh	8%		0.67	0.72	0.84	0.98	1.15	1.34	1.56	1.82	2.13	3.12
Energy selling price (he	R/KWh	6%		0.32	0.34	0.38	0.43	0.48	0.54	0.61	0.68	0.77	1.03
Gate fee	R/t	6%		300	318.00	357.30	401.47	451.09	506.84	569.49	639.88	718.97	962.14
Energy buying price	R/KWh	8%		0.67	0.72	0.84	0.98	1.15	1.34	1.56	1.82	2.13	3.12
Water price	R/m³	6%		11.42	12.11	13.60	15.28	17.17	19.29	21.68	24.36	27.37	36.63
Liquide effluent price	R/t	6%		8.78	9.31	10.46	11.75	13.20	14.83	16.67	18.73	21.04	28.16
Compost	R/t	6%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dumping price (+transp	R/t	6%		510	541	607	682	767	862	968	1,088	1,222	1,636
Nutrients (desulphuriz	R/t	6%		30,000	30,000	33,708.00	37,874.31	42,555.57	47,815.44	53,725.43	60,365.89	67,827.12	90,767.99
Polymer	R/t			30	30	33.20	37.31	41.92	47.10	52.92	59.46	66.81	89.41
A-scalant (polymer)	R/t	6%		75,000	75,000	84,270.00	94,685.77	106,388.93	119,538.61	134,313.58	150,914.74	169,567.80	226,919.96
A-foam (polymer)	R/t	6%		45,000	45,000	50,562.00	56,811.46	63,833.36	71,723.16	80,588.15	90,548.84	101,740.68	136,151.98
Sales					44,482,248	50,491,260	57,328,018	65,108,979	73,967,352	84,055,553	95,548,044	108,644,583	149,988,506
Energy (electricty)					11,939,400	13,926,116	16,243,422	18,946,327	22,098,996	25,776,269	30,065,440	35,068,330	51,526,881
Energy (heat)					4,558,848	5,122,322	5,755,441	6,466,813	7,266,111	8,164,202	9,173,298	10,307,117	13,793,248
Gate fee					27,984,000	31,442,822	35,329,155	39,695,839	44,602,245	50,115,082	56,309,306	63,269,136	84,668,376
Compost					-	-	-	-	-	-	-	-	-
Variable Costs					24,005,359	27,099,398	30,596,990	34,551,530	39,023,596	44,081,938	49,804,601	56,280,200	76,458,023
Electricity					2,966,760	3,460,429	4,036,244	4,707,875	5,491,266	6,405,012	7,470,806	8,713,949	12,803,649
Fresh water					244,525	274,748	308,707	346,863	389,736	437,907	492,032	552,848	739,835
Dumping					19,515,660	21,927,796	24,638,071	27,683,337	31,104,997	34,949,575	39,269,342	44,123,033	59,046,571

Nutrients (desulphurization)					78,000	87,641	98,473	110,644	124,320	139,686	156,951	176,351	235,997
Polymer					414	465	522	587	659	741	832	935	1,252
A-scalant (polymer)					750,000	842,700	946,858	1,063,889	1,195,386	1,343,136	1,509,147	1,695,678	2,269,200
A-foam (polymer)					450,000	505,620	568,115	638,334	717,232	805,881	905,488	1,017,407	1,361,520
Fixed costs & overheads					7,475,139	8,399,066	9,437,190	10,603,627	11,914,235	13,386,835	15,041,447	16,900,570	22,616,775
Salaries		6%			1,920,000	2,157,312	2,423,956	2,723,557	3,060,188	3,438,428	3,863,417	4,340,936	5,809,151
O&M	1% of Capex	6%			1,218,475	1,369,079	1,538,297	1,728,430	1,942,064	2,182,104	2,451,812	2,754,855	3,686,618
Insurance	0.3% of Cape:	6%			609,237.62	684,539	769,148	864,215	971,032	1,091,052	1,225,906	1,377,428	1,843,309
Maintenance	3% of Capex	6%			3,655,425.69	4,107,236	4,614,891	5,185,291	5,826,193	6,546,311	7,355,435	8,264,566	11,059,854
Land Lease		6%			-	-	-	-	-	-	-	-	-
Admin fees		6%			72,000	80,899	90,898	102,133	114,757	128,941	144,878	162,785	217,843
Total investment				-121,847,523									
EBITDA				-121,847,523	13,001,751	14,992,796	17,293,837	19,953,823	23,029,521	26,586,780	30,701,996	35,463,813	50,913,707
Accumolated earnings				-121,847,523	-108,845,772	-79,891,668	-46,496,153	-7,966,719	36,498,622	87,828,850	147,100,258	215,560,080	436,971,328

3MW

Item	Units	Escelation (if not CPI)	Year	0	1	3	5	7	9	11	13	15	20
Inputs and Outputs													
Energy sold (electricty)	KWh/y				25,100,000	25,100,000	25,100,000	25,100,000	25,100,000	25,100,000	25,100,000	25,100,000	25,100,000
Energy sold (heat)	KWh/y				13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000
Waste received	t/y				125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000	125,000
Electricity used	KWh/y				4,500,000	4,500,000	4,500,000	4,500,000	4,500,000	4,500,000	4,500,000	4,500,000	4,500,000
Fresh water used	m^3/y				37,800	37,800	37,800	37,800	37,800	37,800	37,800	37,800	37,800
Liquide effluent	m^3/y				69,900	69,900	69,900	69,900	69,900	69,900	69,900	69,900	69,900
Compost	t/y				19,800	19,800	19,800	19,800	19,800	19,800	19,800	19,800	19,800
Waste for dumping	t/y				50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Nutrients (desulphuriz	t/y				3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Polymer	t/y				21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
A-scalant (polymer)	t/y				10	10	10	10	10	10	10	10	10
A-foam (polymer)	t/y				10	10	10	10	10	10	10	10	10
Variable Rates													
Energy selling price (el	R/KWh	8%		0.67	0.72	0.84	0.98	1.15	1.34	1.56	1.82	2.13	3.12
Energy selling price (he	R/KWh	6%		0.32	0.34	0.38	0.43	0.48	0.54	0.61	0.68	0.77	1.03
Gate fee	R/t	6%		300	318.00	357.30	401.47	451.09	506.84	569.49	639.88	718.97	962.14
Energy buying price	R/KWh	8%		0.67	0.72	0.84	0.98	1.15	1.34	1.56	1.82	2.13	3.12

Water price	R/m³	6%		11.42	12.11	13.60	15.28	17.17	19.29	21.68	24.36	27.37	36.63
Liquide effluent price	R/t	6%		8.78	9.31	10.46	11.75	13.20	14.83	16.67	18.73	21.04	28.16
Compost	R/t	6%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dumping price (+transp	R/t	6%		510	541	607	682	767	862	968	1,088	1,222	1,636
Nutrients (desulphuriz	R/t	6%		30,000	30,000	33,708.00	37,874.31	42,555.57	47,815.44	53,725.43	60,365.89	67,827.12	90,767.99
Polymer	R/t	6%		30	30	33.20	37.31	41.92	47.10	52.92	59.46	66.81	89.41
A-scalant (polymer)	R/t	6%		75,000	75,000	84,270.00	94,685.77	106,388.93	119,538.61	134,313.58	150,914.74	169,567.80	226,919.96
A-foam (polymer)	R/t	6%		45,000	45,000	50,562.00	56,811.46	63,833.36	71,723.16	80,588.15	90,548.84	101,740.68	136,151.98
Sales					62,471,208	70,969,998	80,648,590	91,674,330	104,238,833	118,561,571	134,894,020	153,524,418	212,444,145
Energy (electricty)					18,162,360	21,184,577	24,709,690	28,821,383	33,617,261	39,211,173	45,735,912	53,346,368	78,383,316
Energy (heat)					4,558,848	5,122,322	5,755,441	6,466,813	7,266,111	8,164,202	9,173,298	10,307,117	13,793,248
Gate fee					39,750,000	44,663,100	50,183,459	56,386,135	63,355,461	71,186,196	79,984,810	89,870,932	120,267,580
Compost					-	-	-	-	-	-	-	-	-
Variable Costs					32,058,397	36,160,180	40,792,134	46,023,647	51,933,325	58,610,240	66,153,345	74,683,091	101,196,699
Electricity					3,256,200	3,798,032	4,430,024	5,167,180	6,026,999	7,029,892	8,199,666	9,564,090	14,052,786
Fresh water					457,577	514,133	577,680	649,081	729,308	819,450	920,734	1,034,537	1,384,443
Dumping					27,030,000	30,370,908	34,124,752	38,342,572	43,081,713	48,406,613	54,389,671	61,112,234	81,781,955
Nutrients (desulphurization)					114,000	128,090	143,922	161,711	181,699	204,157	229,390	257,743	344,918
Polymer					621	697	783	880	989	1,111	1,249	1,403	1,878
A-scalant (polymer)					750,000	842,700	946,858	1,063,889	1,195,386	1,343,136	1,509,147	1,695,678	2,269,200
A-foam (polymer)					450,000	505,620	568,115	638,334	717,232	805,881	905,488	1,017,407	1,361,520
Fixed costs & overheads					9,374,261	10,532,919	11,834,788	13,297,568	14,941,147	16,787,873	18,862,854	21,194,303	28,362,758
Salaries		6%			1,920,000	2,157,312	2,423,956	2,723,557	3,060,188	3,438,428	3,863,417	4,340,936	5,809,151
O&M	1% of Capex	6%			1,640,502	1,843,268	2,071,096	2,327,084	2,614,712	2,937,890	3,301,013	3,709,018	4,963,503
Insurance	0.3% of Cape	6%			820,251.19	921,634	1,035,548	1,163,542	1,307,356	1,468,945	1,650,507	1,854,509	2,481,752
Maintenance	3% of Capex	6%			4,921,507.13	5,529,805	6,213,289	6,981,252	7,844,135	8,813,670	9,903,039	11,127,055	14,890,510
Land Lease		6%			-	-	-	-	-	-	-	-	-
Admin fees		6%			72,000	80,899	90,898	102,133	114,757	128,941	144,878	162,785	217,843
Total investment				-164,050,238									
EBITDA				-164,050,238	21,038,550	24,276,899	28,021,667	32,353,115	37,364,360	43,163,458	49,875,821	57,647,023	82,884,687
Accumolated earnings				-164,050,238	-143,011,687	-96,135,802	-42,032,891	20,428,785	92,560,531	175,882,017	272,154,729	383,420,847	743,668,523

5MW (C)

Item	Units	Escelation (If not CPI)	Year	0	1	3	5	7	9	11	13	15	20
Inputs and Outputs													
Energy sold (electricty)	KWh/y				42,400,000	42,400,000	42,400,000	42,400,000	42,400,000	42,400,000	42,400,000	42,400,000	42,400,000
Energy sold (heat)	KWh/y				13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000
Waste received	t/y				210,000	210,000	210,000	210,000	210,000	210,000	210,000	210,000	210,000
Electricity used	KWh/y				5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000	5,600,000
Fresh water used	m³/y				65,400	65,400	65,400	65,400	65,400	65,400	65,400	65,400	65,400
Liquide effluent	m³/y				119,400	119,400	119,400	119,400	119,400	119,400	119,400	119,400	119,400
Compost	t/y				33,100	33,100	33,100	33,100	33,100	33,100	33,100	33,100	33,100
Waste for dumping	t/y				84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000
Nutrients (desulphuriz	t/y				6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Polymer	t/y				36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
A-scalant (polymer)	t/y				10	10	10	10	10	10	10	10	10
A-foam (polymer)	t/y				10	10	10	10	10	10	10	10	10
Variable Rates													
Energy selling price (el	R/KWh	8%		0.67	0.72	0.84	0.98	1.15	1.34	1.56	1.82	2.13	3.12
Energy selling price (he	R/KWh	6%		0.32	0.34	0.38	0.43	0.48	0.54	0.61	0.68	0.77	1.03
Gate fee	R/t	6%		300	318.00	357.30	401.47	451.09	506.84	569.49	639.88	718.97	962.14
Energy buying price	R/KWh	8%		0.67	0.72	0.84	0.98	1.15	1.34	1.56	1.82	2.13	3.12
Water price	R/m³	6%		11.42	12.11	13.60	15.28	17.17	19.29	21.68	24.36	27.37	36.63
Liquide effluent price	R/t	6%		8.78	9.31	10.46	11.75	13.20	14.83	16.67	18.73	21.04	28.16
Compost	R/t	6%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dumping price (+transp	R/t	6%		510	541	607	682	767	852	968	1,088	1,222	1,636
Nutrients (desulphuriz	R/t	6%		30,000	30,000	33,708.00	37,874.31	42,555.57	47,815.44	53,725.43	60,365.89	67,827.12	90,767.99
Polymer	R/t	6%		30	30	33.20	37.31	41.92	47.10	52.92	59.46	66.81	89.41
A-scalant (polymer)	R/t	6%		75,000	75,000	84,270.00	94,685.77	106,388.93	119,538.61	134,313.58	150,914.74	169,567.80	226,919.96
A-foam (polymer)	R/t	6%		45,000	45,000	50,562.00	56,811.46	63,833.36	71,723.16	80,588.15	90,548.84	101,740.68	136,151.98
Sales					102,019,488	115,942,228	131,804,324	149,881,839	170,491,009	193,994,212	220,806,849	251,405,264	348,251,254
Energy (electricty)					30,680,640	35,785,898	41,740,672	48,686,320	56,787,723	66,237,201	77,259,071	90,114,980	132,408,471
Energy (heat)					4,558,848	5,122,322	5,755,441	6,466,813	7,266,111	8,164,202	9,173,298	10,307,117	13,793,248
Gate fee					66,780,000	75,034,008	84,308,211	94,728,706	106,437,174	119,592,809	134,374,480	150,983,166	202,049,535
Compost					-	-	-	-	-	-	-	-	-
Variable Costs					51,644,304	58,200,972	65,596,904	73,940,634	83,354,912	93,978,591	105,968,772	119,503,245	161,482,678
Electricity					4,052,160	4,726,439	5,512,919	6,430,269	7,500,265	8,748,310	10,204,028	11,901,979	17,487,911
Fresh water					791,680	889,532	999,478	1,123,013	1,261,818	1,417,778	1,593,016	1,789,913	2,395,307
Dumping					45,410,400	51,023,125	57,329,584	64,415,520	72,377,279	81,323,110	91,374,647	102,668,553	137,393,684

Nutrients (desulphurization)					189,000	212,380	238,608	268,100	301,237	338,470	380,305	427,311	571,838
Polymer					1,064	1,195	1,343	1,509	1,696	1,905	2,141	2,405	3,219
A-scalant (polymer)					750,000	842,700	946,858	1,063,889	1,195,388	1,343,136	1,509,147	1,695,678	2,269,200
A-foam (polymer)					450,000	505,620	568,115	638,334	717,232	805,881	905,488	1,017,407	1,361,520
Fixed costs & overheads					13,359,634	15,010,884	16,866,230	18,950.896	21,293,226	23,925,069	26,882,208	30,204,849	40,420,901
Salaries		6%			1,920,000	2,157,312	2,423,956	2,723,557	3,060,188	3,438,428	3,863,417	4,340,936	5,809,151
O&M	1% of Capex	6%			2,526,141	2,838,372	3,189,195	3,583,379	4,026,285	4,523,933	5,083,092	5,711,362	7,643,090
Insurance	0.3% of Cape:	6%			1,263,070.40	1,419,186	1,594,597	1,791,690	2,013,142	2,261,967	2,541,546	2,855,681	3,821,545
Maintenance	3% of Capex	6%			7,578,422.42	8,515,115	9,367,584	10,750.137	12,078,854	13,571,800	15,249,275	17,134,085	22,929,271
Land Lease		6%			-	-	-	-	-	-	-	-	-
Admin fees		6%			72,000	80,899	90,898	102,133	114,757	128,941	144,878	162,785	217,843
Total investment				-252,614,081									
EBITDA				-252,614,081	37,015,550	42,730,371	49,341,190	56,990,309	65,842,870	76,090,552	87,955,869	101,697,170	146,347,675
Accumolated earnings				-252,614,081	-215,598,530	-133,099,105	-37,842,532	72,173,994	199,271,713	346,141,457	515,903,090	712,174,582	1,348,052,000

5MW (P&S)

Item	Units	Escelation (If not CPI)	Year	0	1	3	5	7	9	11	13	15	20
Inputs and Outputs													
Energy sold (electricty)	KWh/y				28,200,000	28,200,000	28,200,000	28,200,000	28,200,000	28,200,000	28,200,000	28,200,000	28,200,000
Energy sold (heat)	KWh/y				13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000
Waste received	t/y				132,000	132,000	132,000	132,000	132,000	132,000	132,000	132,000	132,000
Electricity used	KWh/y				3,160,000	3.160,000	3,160,000	3,160,000	3,160,000	3,160,000	3,160,000	3,160,000	3,160,000
Fresh water used	m³/y				39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Liquide effluent	m³/y				72,900	72,900	72,900	72,900	72,900	72,900	72,900	72,900	72,900
Compost	t/y				20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800
Waste for dumping	t/y				52,800	52,800	52,800	52,800	52,800	52,800	52,800	52,800	52,800
Nutrients (desulphuriz	t/y				4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Polymer	t/y				23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0
A-scalant (polymer)	t/y				10	10	10	10	10	10	10	10	10
A-foam (polymer)	t/y				10	10	10	10	10	10	10	10	10
Variable Rates													
Energy selling price (el	R/KWh	8%		0.84	0.91	1.06	1.23	1.44	1.68	1.96	2.28	2.66	3.92
Energy selling price (he	R/KWh	6%		0.32	0.34	0.38	0.43	0.48	0.54	0.61	0.68	0.77	1.03
Gate fee	R/t	6%		300	318.00	357.30	401.47	451.09	506.84	569.48	639.88	718.57	962.14
Energy buying price	R/KWh	8%		0.84	0.91	1.06	1.23	1.44	1.68	1.96	2.28	2.66	3.92

Water price	R/m³	6%		11.42	12.11	13.60	15.28	17.17	19.29	21.68	24.36	27.37	36.63
Liquide effluent price	R/t	6%		8.78	9.31	10.46	11.75	13.20	14.83	16.67	18.73	21.04	28.16
Compost	R/t	6%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dumping price (+transp	R/t	6%		510	541	607	682	767	862	968	1,088	1,222	1,636
Nutrients (desulphuriz	R/t	6%		30,000	30,000	33,708.00	37,874.31	42,555.57	47,815.44	53,725.43	60,365.89	67,827.12	90,767.99
Polymer	R/t	6%		30	30	33.20	37.31	41.92	47.10	52.92	59.46	66.81	89.41
A-scalant (polymer)	R/t	6%		75,000	75,000	84,270.00	94,685.77	106,388.93	119,538.61	134,313.58	150,914.74	169,567.80	226,919.96
A-foam (polymer)	R/t	6%		45,000	45,000	50,562.00	56,811.46	63,833.36	71,723.16	80,588.15	90,548.84	101,740.68	136,151.98
Sales					72,117,888	82,126,613	93,554,617	106,607,641	121,521,899	138,568,690	158,059,704	180,353,164	251,204,566
Energy (electricty)					25,583,040	29,840,058	34,805,443	40,597,069	47,352,422	55,231,865	64,422,447	75,142,342	110,408,753
Energy (heat)					4,558,848	5,122,322	5,755,441	6,466,813	7,266,111	8,164,202	9,173,298	10,307,117	13,793,248
Gate fee					41,976,000	47,164,234	52,993,733	59,543,758	66,903,367	75,172,623	84,463,959	94,903,704	127,002,565
Compost					-	-	-	-	-	-	-	-	-
Variable Costs					33,203,234	37,429,829	42,199,269	47,582,027	53,657,870	60,517,086	68,261,892	77,008,034	104,158,030
Electricity					2,866,752	3,343,780	3,900,184	4,549,175	5,306,158	6,189,103	7,218,969	8,420,206	12,372,045
Fresh water					472,103	530,455	596,019	669,687	752,460	845,464	949,964	1,067,379	1,428,394
Dumping					28,543,680	32,071,679	36,035,738	40,489,756	45,494,289	51,117,384	57,435,492	64,534,519	86,361,744
Nutrients (desulphurization)					120,000	134,832	151,497	170,222	191,262	214,902	241,464	271,306	363,072
Polymer					680	764	858	964	1,083	1,217	1,368	1,537	2,056
A-scalant (polymer)					750,000	842,700	946,858	1,063,889	1,195,386	1,343,136	1,509,147	1,695,678	2,269,200
A-foam (polymer)					450,000	505,620	568,115	638,334	717,232	805,881	905,488	1,017,407	1,361,520
Fixed costs & overheads					9,954,292	11,184,642	12,567,064	14,120,353	15,865,629	17,826,621	20,029,991	22,505,698	30,117,701
Salaries		6%			1,920,000	2,157,312	2,423,956	2,723,557	3,060,188	3,438,428	3,863,417	4,340,936	5,809,151
O&M	1% of Capex	6%			1,769,398	1,988,096	2,233,824	2,509,925	2,820,152	3,168,723	3,560,377	4,000,439	5,353,490
Insurance	0.3% of Cape	6%			884,699.10	994,048	1,116,912	1,254,963	1,410,076	1,584,361	1,780,188	2,000,220	2,676,745
Maintenance	3% of Capex	6%			5,308,194.60	5,964,287	6,701,473	7,529,775	8,460,456	9,506,168	10,681,130	12,001,318	16,060,471
Land Lease		6%			-	-	-	-	-	-	-	-	-
Admin fees		6%			72,000	80,899	90,898	102,133	114,757	128,941	144,878	162,785	217,843
Total investment				-176,939,820									
EBITDA				-176,939,820	28,960,382	33,512,142	38,788,283	44,905,260	51,998,400	60,224,983	69,767,821	80,839,432	116,928,835
Accumolated earnings				-176,939,820	-147,979,438	-83,314,966	-8,473,887	78,165,059	178,483,993	294,668,206	429,255,364	585,192,756	1,092,294,817

5MW (P)

Item	Units	Escelation (if not CPI)	Year	0	1	3	5	7	9	11	13	15	20
Inputs and Outputs													
Energy sold (electricty)	KWh/y				8,800,000	8,800,000	8,800,000	8,800,000	8,800,000	8,800,000	8,800,000	8,800,000	8,800,000
Energy sold (heat)	KWh/y				9,300,000	9,300,000	9,300,000	9,300,000	9,300,000	9,300,000	9,300,000	9,300,000	9,300,000
Waste received	t/y				44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
Electricity used	KWh/y				650,000	650,000	650,000	650,000	650,000	650,000	650,000	650,000	650,000
Fresh water used	m³/y				13,600	13,600	13,600	13,600	13,600	13,600	13,600	13,600	13,600
Liquide effluent	m³/y				24,900	24,900	24,900	24,900	24,900	24,900	24,900	24,900	24,900
Compost	t/y				4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100
Waste for dumping	t/y				17,600	17,600	17,600	17,600	17,600	17,600	17,600	17,600	17,600
Nutrients (desulphuriz	t/y				1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Polymer	t/y				8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
A-scalant (polymer)	t/y				10	10	10	10	10	10	10	10	10
A-foam (polymer)	t/y				10	10	10	10	10	10	10	10	10
Variable Rates													
Energy selling price (el	R/KWh	8%		1.16	1.25	1.46	1.70	1.99	2.32	2.70	3.15	3.68	5.41
Energy selling price (he	R/KWh	6%		0.32	0.34	0.38	0.43	0.48	0.54	0.61	0.68	0.77	1.03
Gate fee	R/t	6%		300	318.00	357.30	401.47	451.09	506.84	569.49	639.88	718.97	962.14
Energy buying price	R/KWh	8%		1.16	1.25	1.46	1.70	1.99	2.32	2.70	3.15	3.68	5.41
Water price	R/m³	6%		11.42	12.11	13.60	15.28	17.17	19.29	21.68	24.36	27.37	36.63
Liquide effluent price	R/t	6%		8.78	9.31	10.46	11.75	13.20	14.83	16.67	18.73	21.04	28.16
Compost	R/t	6%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dumping price (+transp	R/t	6%		510	541	607	682	767	862	968	1,088	1,222	1,636
Nutrients (desulphuriz	R/t	6%		30,000	30,000	33,708.00	37,874.31	42,555.57	47,815.44	53,725.43	60,365.89	67,827.12	90,767.99
Polymer	R/t	6%		30	30	33.20	37.31	41.92	47.10	52.92	59.46	66.81	89.41
A-scalant (polymer)	R/t	6%		75,000	75,000	84,270.00	94,685.77	106,388.93	119,558.61	134,313.58	150,914.74	169,567.80	226,919.96
A-foam (polymer)	R/t	6%		45,000	45,000	50,562.00	56,811.46	63,833.36	71,723.16	80,588.15	90,548.84	101,740.68	136,151.98
Sales					28,171,200	32,125,015	36,646,038	41,817,441	47,734,851	54,508,248	62,264,167	71,148,228	99,457,674
Energy (electricty)					11,024,640	12,859,140	14,998,901	17,494,718	20,405,839	23,801,371	27,761,919	32,381,502	47,579,051
Energy (heat)					3,154,560	3,544,464	3,982,559	4,474,804	5,027,889	5,649,337	6,347,595	7,132,157	9,544,435
Gate fee					13,992,000	15,721,411	17,664,578	19,847,919	22,301,122	25,057,541	28,154,653	31,634,568	42,334,188
Compost					-	-	-	-	-	-	-	-	-
Variable Costs					11,732,747	13,217,768	14,892,136	16,780,221	18,909,564	21,311,296	24,020,617	27,077,331	36,549,149
Electricity					814,320	949,823	1,107,873	1,292,223	1,507,249	1,758,056	2,050,596	2,391,816	3,314,362
Fresh water					164,631	184,979	207,842	233,532	262,396	294,829	331,269	372,214	498,107
Dumping					9,514,560	10,690,560	12,011,913	13,496,585	15,164,763	17,039,128	19,145,164	21,511,906	28,787,248

Nutrients (desulphurization)					39,000	43,820	49,237	55,322	62,160	69,843	78,476	88,175	117,998
Polymer					236	266	298	335	377	423	476	534	715
A-scalant (polymer)					750,000	842,700	946,858	1,063,889	1,195,386	1,343,136	1,509,147	1,695,678	2,269,200
A-foam (polymer)					450,000	505,620	568,115	638,334	717,232	805,881	905,488	1,017,407	1,361,520
Fixed costs & overheads					7,537,720	8,469,382	9,516,198	10,692,400	12,013,981	13,498,909	15,167,374	17,042,061	22,806,122
Salaries		6%			1,920,000	2,157,312	2,423,956	2,723,557	3,060,188	3,438,428	3,863,417	4,340,936	5,809,151
O&M	1% of Capex	6%			1,232,382	1,384,705	1,555,854	1,748,158	1,964,230	2,207,009	2,479,795	2,786,298	3,728,695
Insurance	0.3% of Cape:	6%			616,191.12	692,352	777,927	874,079	982,115	1,103,504	1,239,898	1,393,149	1,864,348
Maintenance	3% of Capex	6%			3,697,146.72	4,154,114	4,667,563	5,244,473	5,892,690	6,621,027	7,439,386	8,358,894	11,186,085
Land Lease		6%			-	-	-	-	-	-	-	-	-
Admin fees		6%			72,000	80,899	90,898	102,133	114,757	128,941	144,878	162,785	217,843
Total investment				-123,238,224									
EBITDA				-123,238,224	8,900,733	10,437,865	12,237,704	14,344,820	16,811,307	19,698,044	23,076,176	27,028,836	40,102,402
Accumolated earnings				-123,238,224	-114,337,491	-94,260,643	-70,720,616	-43,126,009	-10,785,143	27,110,858	71,507,827	123,511,636	295,832,136

10MW (P)

Item	Units	Escelation (if not CPI)	Year	0	1	3	5	7	9	11	13	15	20
Inputs and Outputs													
Energy sold (electricty)	KWh/y				17,600,000	17,600,000	17,600,000	17,600,000	17,600,000	17,600,000	17,600,000	17,600,000	17,600,000
Energy sold (heat)	KWh/y				13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000	13,440,000
Waste received	t/y				88,000	88,000	88,000	88,000	88,000	88,000	88,000	88,000	88,000
Electricity used	KWh/y				775,000	775,000	775,000	775,000	775,000	775,000	775,000	775,000	775,000
Fresh water used	m^3/y				25,700	25,700	25,700	25,700	25,700	25,700	25,700	25,700	25,700
Liquide effluent	m^3/y				48,800	48,800	48,800	48,800	48,800	48,800	48,800	48,800	48,800
Compost	t/y				12,700	12,700	12,700	12,700	12,700	12,700	12,700	12,700	12,700
Waste for dumping	t/y				36,100	36,100	36,100	36,100	36,100	36,100	36,100	36,100	36,100
Nutrients (desulphuriz	t/y				2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Polymer	t/y				14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
A-scalant (polymer)	t/y				10	10	10	10	10	10	10	10	10
A-foam (polymer)	t/y				10	10	10	10	10	10	10	10	10
Variable Rates													
Energy selling price (el	R/KWh	8%		1.16	1.25	1.46	1.70	1.99	2.32	2.70	3.15	3.68	5.41
Energy selling price (he	R/KWh	6%		0.32	0.34	0.38	0.43	0.48	0.54	0.61	0.68	0.77	1.03
Gate fee	R/t	6%		300	318.00	357.30	401.47	451.09	506.84	569.49	639.88	718.97	962.14
Energy buying price	R/KWh	8%		1.16	1.25	1.46	1.70	1.99	2.32	2.70	3.15	3.68	5.41

Water price	R/m³	6%	11.42	12.11	13.60	15.28	17.17	19.29	21.68	24.36	27.37	36.63
Liquide effluent price	R/t	6%	8.78	9.31	10.46	11.75	13.20	14.83	16.67	[illegible]	21.04	28.16
Compost	R/t	6%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dumping price (+transp	R/t	6%	510	541	607	682	767	862	968	1,088	1,222	1,636
Nutrients (desulphuriz	R/t	6%	30,000	30,000	33,708.00	37,874.31	42,555.57	47,815.44	53,725.43	60,365.89	67,827.12	90,767.99
Polymer	R/t	6%	30	30	33.20	37.31	41.92	47.10	52.92	59.46	66.81	89.41
A-scalant (polymer)	R/t	6%	75,000	75,000	84,270.00	94,685.77	106,388.93	119,538.61	134,313.58	150,914.74	169,567.80	226,919.96
A-foam (polymer)	R/t	6%	45,000	45,000	50,562.00	56,811.46	63,833.36	71,723.16	80,588.15	90,548.84	101,740.68	136,151.98
Sales				54,592,128	62,283,424	71,082,398	81,152,088	92,680,034	105,882,026	121,006,442	138,339,258	193,619,726
Energy (electricty)				22,049,290	25,718,280	29,997,802	34,989,436	40,811,678	47,602,742	55,523,838	64,763,005	95,158,101
Energy (heat)				4,558,848	5,122,322	5,755,441	6,466,813	7,266,111	8,164,202	9,173,298	10,307,117	13,793,248
Gate fee				27,984,000	31,442,822	35,329,155	39,695,839	44,602,245	50,115,082	56,309,306	63,269,136	84,668,376
Compost				-	-	-	-	-	-	-	-	-
Variable Costs				22,076,097	24,846,258	27,985,726	31,478,825	35,435,551	39,892,302	44,912,705	50,568,559	68,046,015
Electricity				970,920	1,132,481	1,320,926	1,540,728	1,797,105	2,098,143	2,444,942	2,851,780	4,190,200
Fresh water				311,104	349,556	392,761	441,306	495,852	557,139	626,002	703,375	941,275
Dumping				19,515,660	21,927,796	24,638,071	27,683,337	31,104,997	34,949,575	39,269,342	44,123,033	59,046,571

Nutrients (desulphurization)				78,000	87,641	98,473	110,644	124,320	139,686	156,951	176,351	235,997
Polymer				414	465	522	587	659	741	832	935	1,252
A-scelant (polymer)				750,000	842,700	946,858	1,063,889	1,195,386	1,343,136	1,509,147	1,695,678	2,269,200
A-foam (polymer)				450,000	505,620	568,115	638,334	717,232	805,881	905,488	1,017,407	1,361,520
Fixed costs & overheads				11,388,212	12,795,795	14,377,355	16,154,397	18,151,080	20,394,554	22,915,320	25,747,654	34,456,169
Salaries		6%		1,920,000	2,157,312	2,423,956	2,723,557	3,060,188	3,438,428	3,863,417	4,340,936	5,809,151
O&M	1% of Capex	6%		2,088,047	2,346,130	2,636,111	2,961,935	3,328,030	3,739,374	4,201,561	4,720,874	6,317,594
Insurance	0.3% of Cape	6%		1,044,023.57	1,173,065	1,318,056	1,480,967	1,664,015	1,869,687	2,100,781	2,360,437	3,158,797
Maintenance	3% of Capex	6%		6,264,141.44	7,038,389	7,908,334	8,885,804	9,984,090	11,218,123	12,604,683	14,162,622	18,952,783
Land Lease		6%		-	-	-	-	-	-	-	-	-
Admin fees		6%		72,000	80,899	90,898	102,133	114,757	128,941	144,878	162,785	217,843
Total investment			-208,804,715									
EBITDA			-208,804,715	21,127,819	24,641,371	28,739,316	33,518,866	39,093,403	45,595,171	53,178,416	62,023,046	91,117,542
Accumolated earnings			-208,804,715	-187,676,896	-140,218,470	-84,867,585	-20,311,506	54,980,868	142,795,338	245,214,767	364,668,512	757,601,804

Appendix 7: Atlantis Foundries waste to energy project scenarios model main input and output summary

2MW

Model date	18.12.14			
Project name	Atlantis foundries 2MW			
Contact person	Yoav Shmulevich			
Substrate	SSO (Source Separated Organic)			
Organic fraction	60.0%			
Substrate flow	251.43	ton/day	88,000	ton/year
Biogas production	24,000	m3/day	1,000	m3/h
Electricity generation mode	Peak standard and low			
Electricity generation hours	24	hour/day		
Energy production (after parasitic load)	16,500,000	KWh/year		
Power over continues operation	2.52	MW		
Power over specific operation	2.06	MW		
Heat available	20,400,000	KWh/year		
Heat used	13,440,000	KWh/year		
Liquid effluent production	48,700	m^3/year		
Solid effluent production - Compost	12,800	ton/year		
Waste rejects for dumping/recycling	36,100	ton/year		
Polymers	37	ton/year		
Gate fee	318.00	Rand/ton		
Electricity selling\buying price	0.72	Rand/KWh		
Heat selling price	0.34	Rand/KWh		
Recyclables/rejects selling price (+transportation to vissershok)	-540.6	Rand/ton		
Compost \ organic fertilizer selling price	0.00	Rand/ton		
Water price	12.11	Rand/m^3		
Liquid effluent sewage discharge price	9.31	Rand/m^3		
Polymers weighted average price	34,929	Rand/ton		
Salaries	1,920,000	Rand		
O&M	1,218,475	Rand		
Insurance	609,238	Rand		
Maintenance	3,655,426	Rand		

Land Lease	-	Rand		
Admin fees	72,000	Rand		
Capex	121,847,523	Rand		
Sales (year1)	44,482,248	Rand		
Variable Costs (year1)	24,005,359	Rand		
Fixed costs & overheads (year1)	7,475,139	Rand		
EBITDA (year1)	13,001,751	Rand		
Simple payback	7.4	Years		
IRR 10	7%			
IRR 20	16%			
NPV interest	8%	CPI	6%	
NPV 10	-4,093,672	Rand		
NPV 20	99,212,451	Rand		

3MW

Model date	18.12.14			
Project name	Atlantis foundries 3MW			
Contact person	Yoav Shmulevich			
Substrate	SSO (Source Separated Organic)			
Organic fraction	60.0%			
Substrate flow	357.14	ton/day	125,000	ton/year
Biogas production	36,000	m3/day	1,500	m3/h
Electricity generation mode	Peak standard and low			
Electricity generation hours	24	hour/day		
Energy production (after parasitic load)	25,100,000	KWh/year		
Power over continues operation	3.61	MW		
Power over specific operation	3.05	MW		
Heat available	29,200,000	KWh/year		
Heat used	13,440,000	KWh/year		
Liquid effluent production	69,900	m^3/year		
Solid effluent production - Compost	19,800	ton/year		
Waste rejects for dumping/recycling	50,000	ton/year		
Polymers	45	ton/year		
Gate fee	318.00	Rand/ton		
Electricity selling\buying price	0.72	Rand/KWh		
Heat selling price	0.34	Rand/KWh		
Recyclables/rejects selling price (+transportation to vissershok)	-540.6	Rand/ton		
Compost \ organic fertilizer selling price	0.00	Rand/ton		
Water price	12.11	Rand/m^3		
Liquid effluent sewage discharge price	9.31	Rand/m^3		
Polymers weighted average price	29,344	Rand/ton		
Salaries	1,920,000	Rand		
O&M	1,640,502	Rand		
Insurance	820,251	Rand		

Maintenance	4,921,507	Rand		
Land Lease	-	Rand		
Admin fees	72,000	Rand		
Capex	164,050,238	Rand		
Sales (year1)	62,471,208	Rand		
Variable Costs (year1)	32,058,397	Rand		
Fixed costs & overheads (year1)	9,374,261	Rand		
EBITDA (year1)	21,038,550	Rand		
Simple payback	6.4	Years		
IRR 10	11%			
IRR 20	18%			
NPV interest	8%	CPI	6%	
NPV 10	24,301,511	Rand		
NPV 20	192,249,015	Rand		

5MW (C)

Model date	19.12.14			
Project name	Atlantis foundries 5MW			
Contact person	Yoav Shmulevich			
Substrate	SSO (Source Separated Organic)			
Organic fraction	60.0%			
Substrate flow	600.00	ton/day	210,000	ton/year
Biogas production	60,000	m3/day	2,500	m3/h
Electricity generation mode	Peak standard and low			
Electricity generation hours	24	hour/day		
Energy production (after parasitic load)	42,400,000	KWh/year		
Power over continues operation	5.00	MW		
Power over specific operation	6.00	MW		
Heat available	46,700,000	KWh/year		
Heat used	13,440,000	KWh/year		
Liquid effluent production	119,400	m^3/year		
Solid effluent production - Compost	33,100	ton/year		
Waste rejects for dumping/recycling	84,000	ton/year		
Polymers	62	ton/year		
Gate fee	318.00	Rand/ton		
Electricity selling\buying price	0.72	Rand/KWh		
Heat selling price	0.34	Rand/KWh		
Recyclables/rejects selling price (+transportation to vissershok)	-540.6	Rand/ton		
Compost \ organic fertilizer selling price	0.00	Rand/ton		
Water price	12.11	Rand/m^3		
Liquid effluent sewage discharge price	9.31	Rand/m^3		
Polymers weighted average price	22,312	Rand/ton		
Salaries	1,920,000	Rand		
O&M	2,526,141	Rand		

Insurance	1,263,070	Rand		
Maintenance	7,578,422	Rand		
Land Lease	-	Rand		
Admin fees	72,000	Rand		

Capex	252,614,081	Rand		
Sales (year1)	102,019,488	Rand		
Variable Costs (year1)	51,644,304	Rand		
Fixed costs & overheads (year1)	13,359,634	Rand		
EBITDA (year1)	37,015,550	Rand		
Simple payback	5.7	Years		
IRR 10	14%			
IRR 20	21%			
NPV interest	8%	CPI	6%	
NPV 10	76,380,580	Rand		
NPV 20	372,685,174	Rand		

5MW (P&S)

Model date	9.12.14			
Project name	Atlantis foundries 5MW peak & standard			
Contact person	Yoav Shmulevich			
Substrate	SSO (Source Separated Organic)			
Organic fraction	60.0%			
Substrate flow	377.14	ton/day	132,000	ton/year
Biogas production	38,400	m3/day	1,600	m3/h
Electricity generation mode	Peak and standard			
Electricity generation hours	16	hour/day		
Energy production (after parasitic load)	28,200,000	KWh/year		
Power over continues operation	5.60	MW		
Power over specific operation	5.04	MW		
Heat available	31,000,000	KWh/year		
Heat used	13,440,000	KWh/year		
Liquid effluent production	72,900	m^3/year		
Solid effluent production - Compost	20,800	ton/year		
Waste rejects for dumping/recycling	52,800	ton/year		
Polymers	47	ton/year		
Gate fee	318.00	Rand/ton		
Electricity selling\buying price	0.91	Rand/KWh		
Heat selling price	0.34	Rand/KWh		
Recyclables/rejects selling price (+transportation to vissershok)	-540.6	Rand/ton		
Compost \ organic fertilizer selling price	0.00	Rand/ton		
Water price	12.11	Rand/m^3		
Liquid effluent sewage discharge price	9.31	Rand/m^3		
Polymers weighted average price	28,100	Rand/ton		
Salaries	1,920,000	Rand		
O&M	1,769,398	Rand		

Insurance	884,699	Rand		
Maintenance	5,308,195	Rand		
Land Lease	-	Rand		
Admin fees	72,000	Rand		
Capex	176,939,820	Rand		
Sales (year1)	72,117,888	Rand		
Variable Costs (year1)	33,203,214	Rand		
Fixed costs & overheads (year1)	9,954,292	Rand		
EBITDA (year1)	28,960,382	Rand		
Simple payback	5.2	Years		
IRR 10	17%			
IRR 20	23%			
NPV interest	8%	CPI	6%	
NPV 10	80,207,659	Rand		
NPV 20	315,845,788	Rand		

5MW (P)

Model date	9.12.14			
Project name	Atlantis foundries 5MW peak			
Contact person	Yoav Shmulevich			
Substrate	SSO (Source Separated Organic)			
Organic fraction	60.0%			
Substrate flow	125.71	ton/day	44,000	ton/year
Biogas production	12,000	m3/day	500	m3/h
Electricity generation mode	Peak only			
Electricity generation hours	5	hour/day		
Energy production (after parasitic load)	8,800,000	KWh/year		
Power over continues operation	5.40	MW		
Power over specific operation	5.00	MW		
Heat available	9,300,000	KWh/year		
Heat used	9,300,000	KWh/year		
Liquid effluent production	24,900	m^3/year		
Solid effluent production - Compost	4,100	ton/year		
Waste rejects for dumping/recycling	17,600	ton/year		
Polymers	29	ton/year		
Gate fee	318.00	Rand/ton		
Electricity selling\buying price	1.25	Rand/KWh		
Heat selling price	0.34	Rand/KWh		
Recyclables/rejects selling price (+transportation to vissershok)	-540.6	Rand/ton		
Compost \ organic fertilizer selling price	0.00	Rand/ton		
Water price	12.11	Rand/m^3		
Liquid effluent sewage discharge price	9.31	Rand/m^3		
Polymers weighted average price	42,295	Rand/ton		
Salaries	1,920,000	Rand		
O&M	1,232,382	Rand		

Insurance	616,191	Rand		
Maintenance	3,697,147	Rand		
Land Lease	-	Rand		
Admin fees	72,000	Rand		
Capex	123,238,224	Rand		
Sales (year1)	28,171,200	Rand		
Variable Costs (year1)	11,732,747	Rand		
Fixed costs & overheads (year1)	7,537,720	Rand		
EBITDA (year1)	8,900,733	Rand		
Simple payback	9.6	Years		
IRR 10	1%			
IRR 20	11%			
NPV interest	8%	CPI	6%	
NPV 10	- 36,909,135	Rand		
NPV 20	42,053,511	Rand		

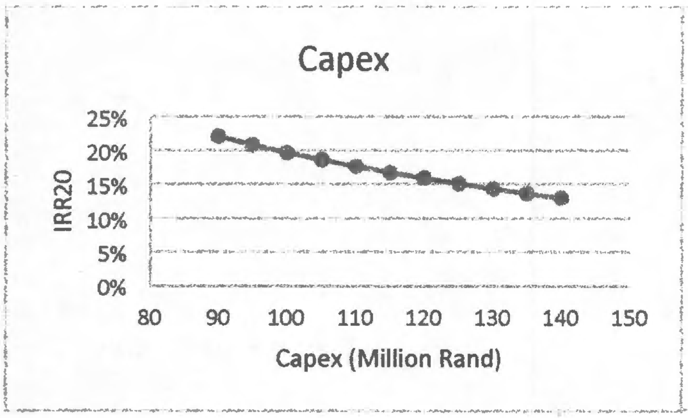
10MW (P)

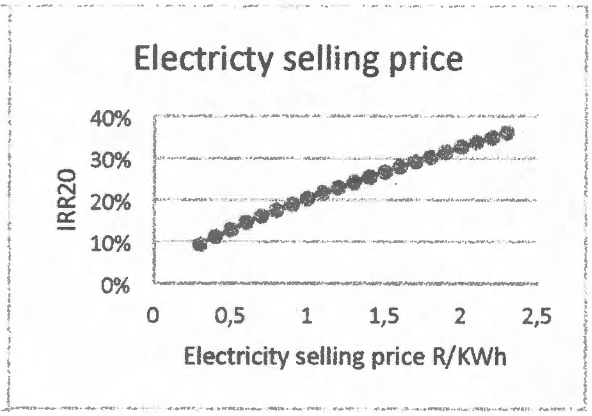
Model date	9.12.14			
Project name	Atlantis foundries 10MW peak			
Contact person	Yoav Shmulevich			
Substrate	SSO (Source Separated Organic)			
Organic fraction	60.0%			
Substrate flow	251.43	ton/day	88,000	ton/year
Biogas production	24,000	m3/day	1,000	m3/h
Electricity generation mode	Peak only			
Electricity generation hours	5	hour/day		
Energy production (after parasitic load)	17,600,000	KWh/year		
Power over continues operation	10.50	MW		
Power over specific operation	10.04	MW		
Heat available	18,000,000	KWh/year		
Heat used	13,440,000	KWh/year		
Liquid effluent production	48,800	m^3/year		
Solid effluent production - Compost	12,700	ton/year		
Waste rejects for dumping/recycling	36,100	ton/year		
Polymers	37	ton/year		
Gate fee	318.00	Rand/ton		
Electricity selling\buying price	1.25	Rand/KWh		
Heat selling price	0.34	Rand/KWh		
Recyclables/rejects selling price (+transportation to vissershok)	-540.6	Rand/ton		
Compost \ organic fertilizer selling price	0.00	Rand/ton		
Water price	12.11	Rand/m^3		
Liquid effluent sewage discharge price	9.31	Rand/m^3		
Polymers weighted average price	34,929	Rand/ton		
Salaries	1,920,000	Rand		
O&M	2,088,047	Rand		

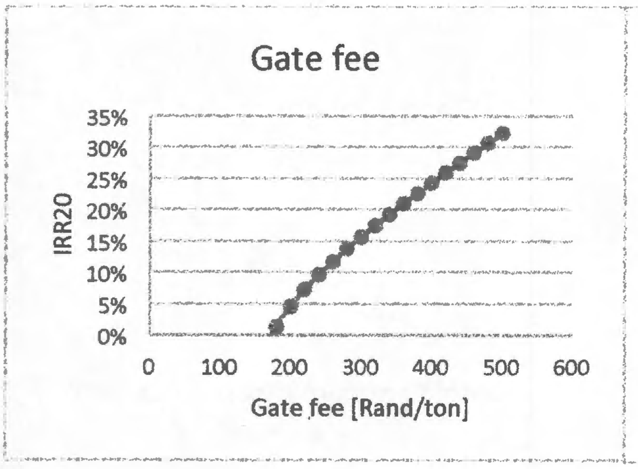
Insurance	1,044,024	Rand		
Maintenance	6,264,141	Rand		
Land Lease	-	Rand		
Admin fees	72,000	Rand		
Capex	208,804,715	Rand		
Sales (year1)	54,592,128	Rand		
Variable Costs (year1)	22,076,097	Rand		
Fixed costs & overheads (year1)	11,388,212	Rand		
EBITDA (year1)	21,127,819	Rand		
Simple payback	7.6	Years		
IRR 10	7%			
IRR 20	15%			
NPV interest	8%	CPI	6%	
NPV 10	- 12,234,355	Rand		
NPV 20	168,802,433	Rand		

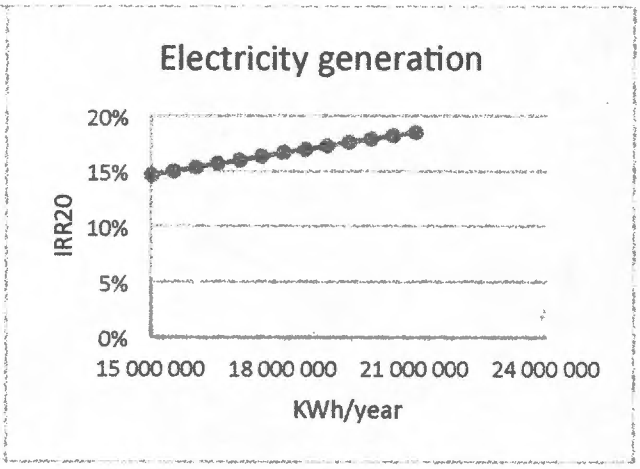
Appendix 8: Atlantis Foundries waste to energy project scenarios feasibility sensitivity

2MW

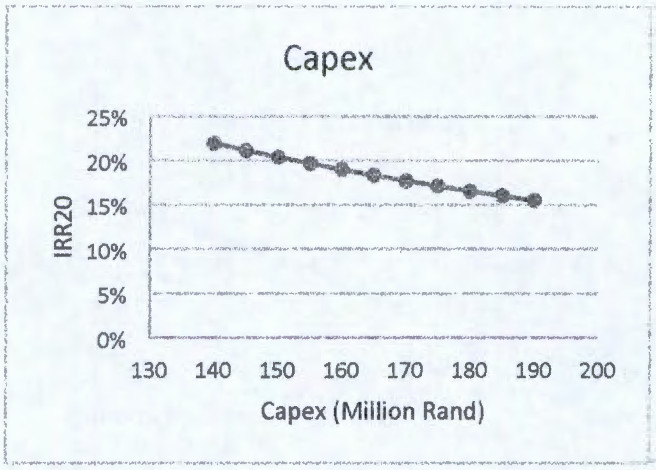


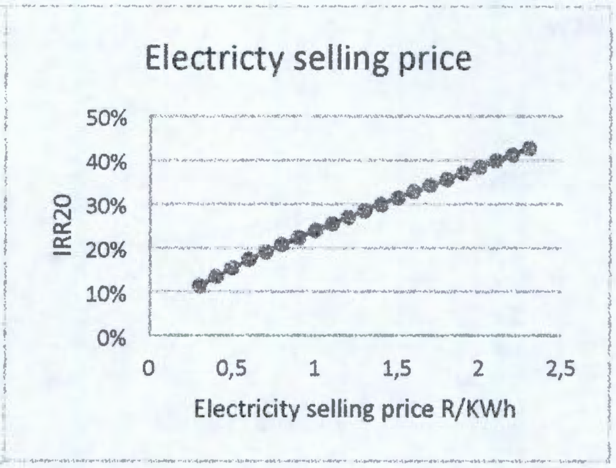


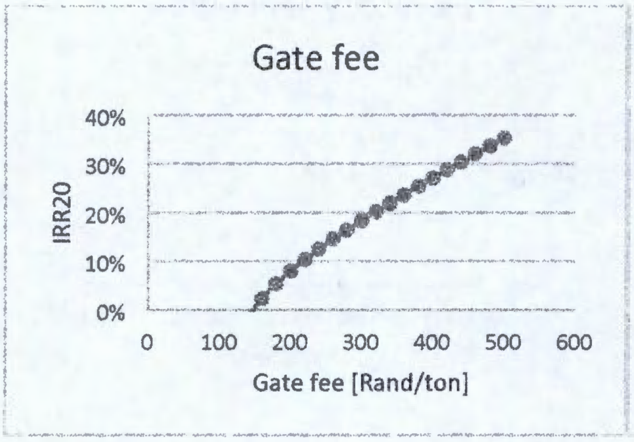


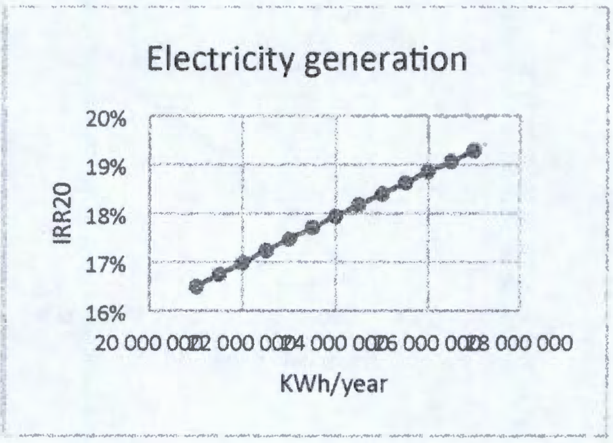


3MW

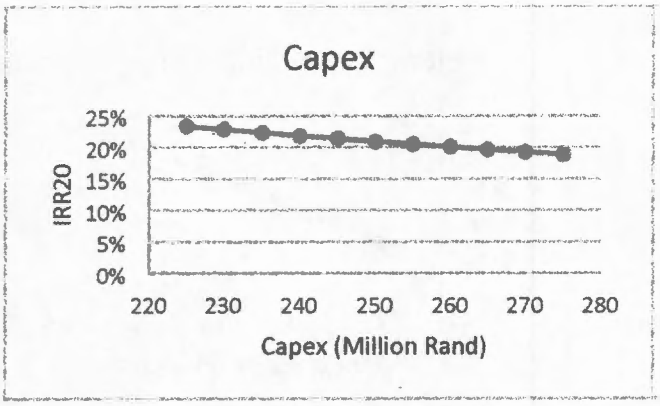

Capex
IRR20
25%
20%
15%
10%
5%
0%
130
140
150
160
170
180
190
200
Capex (Million Rand)

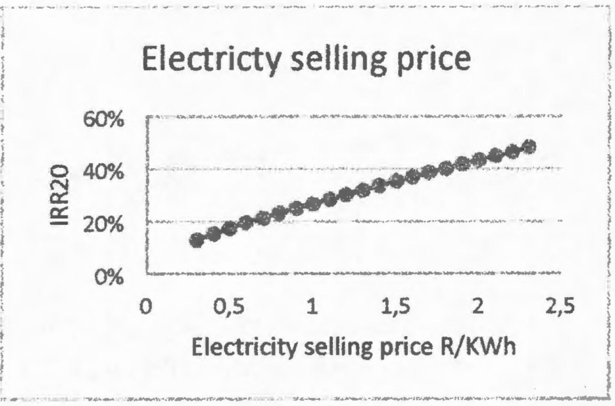

Electricty selling price
IRR20
50%
40%
30%
20%
10%
0%
0
0,5
1
1,5
2
2,5
Electricity selling price R/KWh

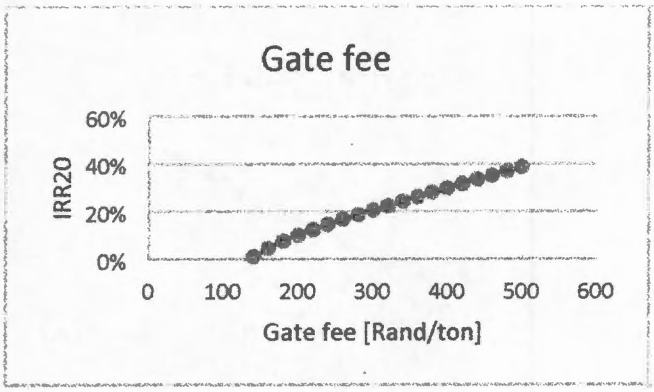

Gate fee
IRR20
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
Gate fee [Rand/ton]

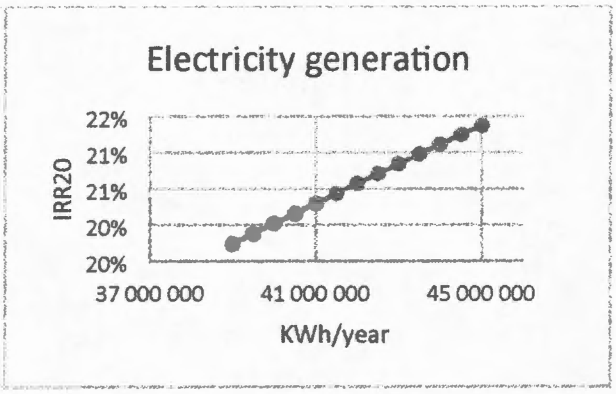

Electricity generation
IRR20
20%
19%
18%
17%
16%
20 000 000
22 000 000
24 000 000
26 000 000
28 000 000
KWh/year

5MW (C)

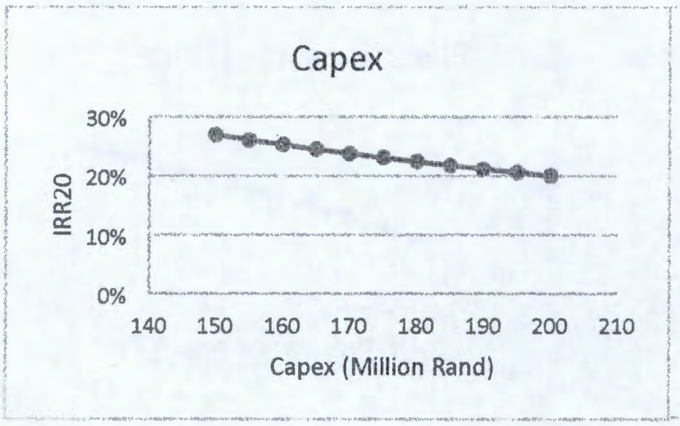

Capex
IRR20
25%
20%
15%
10%
5%
0%
220
230
240
250
260
270
280
Capex (Million Rand)

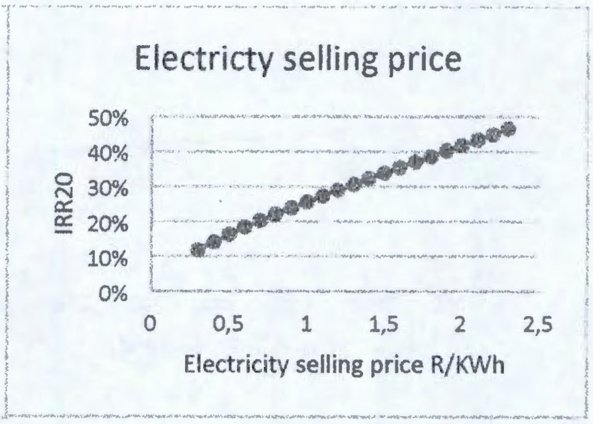

Electricty selling price
IRR20
60%
40%
20%
0%
0
0,5
1
1,5
2
2,5
Electricity selling price R/KWh

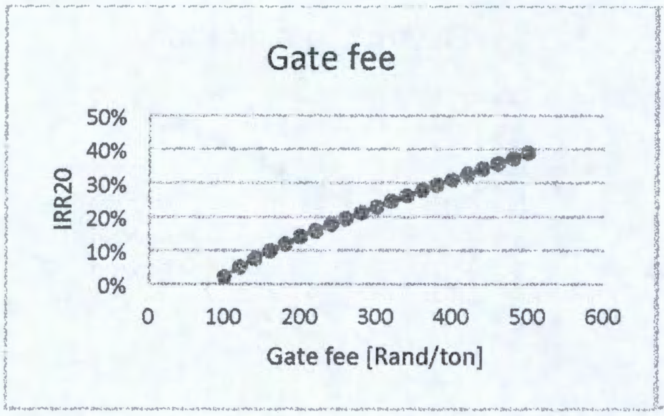

Gate fee
IRR20
60%
40%
20%
0%
0
100
200
300
400
500
600
Gate fee [Rand/ton]

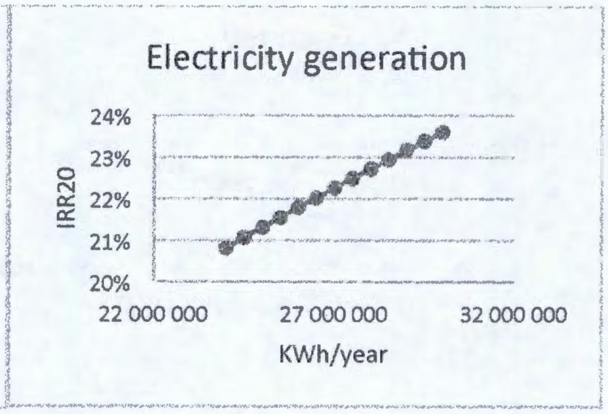

Electricity generation
IRR20
22%
21%
21%
20%
20%
37 000 000
41 000 000
45 000 000
KWh/year

5MW (P&S)

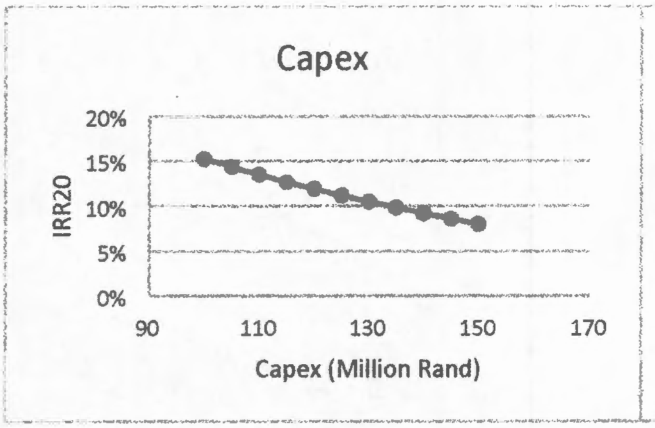

Capex
30%
20%
10%
0%
IRR20
140
150
160
170
180
190
200
210
Capex (Million Rand)

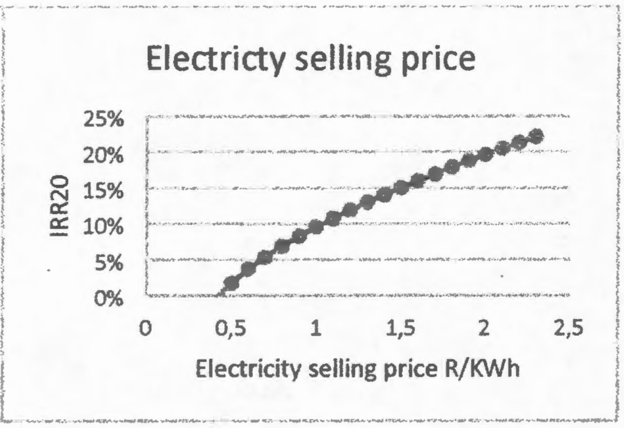

Electricty selling price
50%
40%
30%
20%
10%
0%
IRR20
0
0,5
1
1,5
2
2,5
Electricity selling price R/KWh

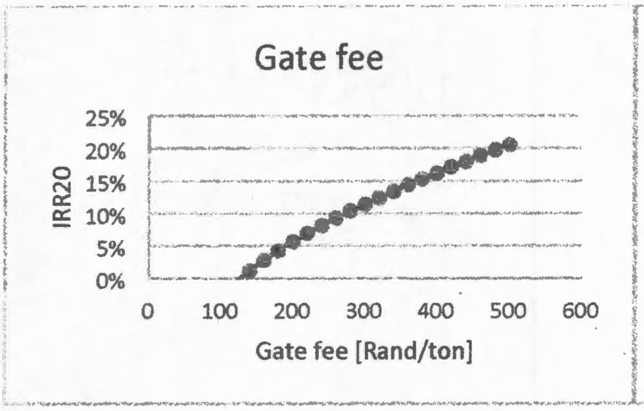

Gate fee
50%
40%
30%
20%
10%
0%
IRR20
0
100
200
300
400
500
600
Gate fee [Rand/ton]

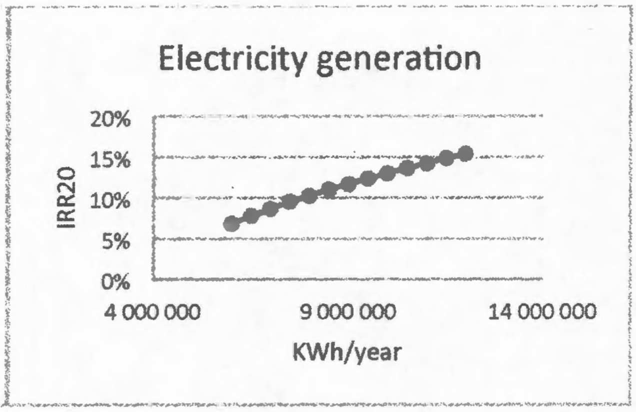

Electricity generation
24%
23%
22%
21%
20%
IRR20
22 000 000
27 000 000
32 000 000
KWh/year

5MW (P)

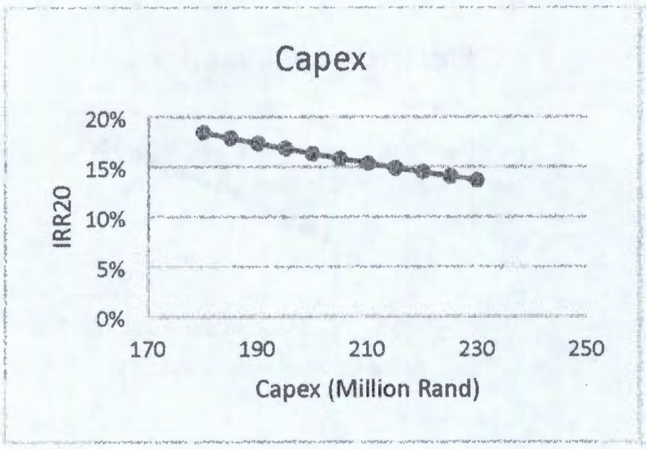

Capex
IRR20
20%
15%
10%
5%
0%
90
110
130
150
170
Capex (Million Rand)

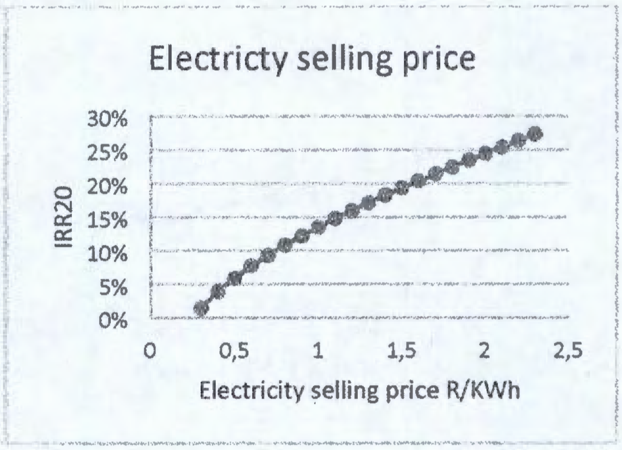

Electricty selling price
IRR20
25%
20%
15%
10%
5%
0%
0
0,5
1
1,5
2
2,5
Electricity selling price R/KWh

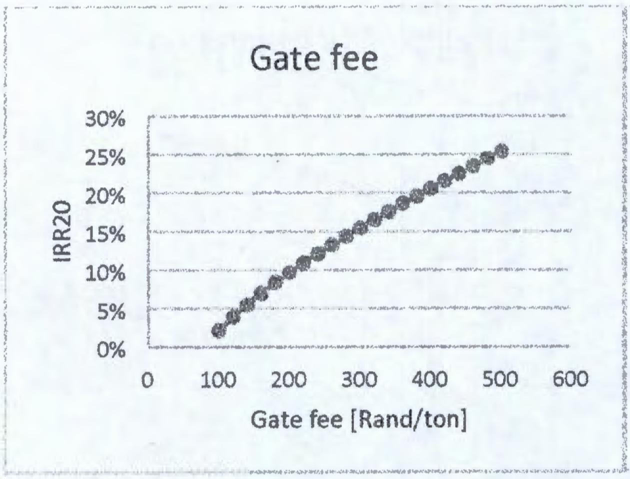

Gate fee
IRR20
25%
20%
15%
10%
5%
0%
0
100
200
300
400
500
600
Gate fee [Rand/ton]

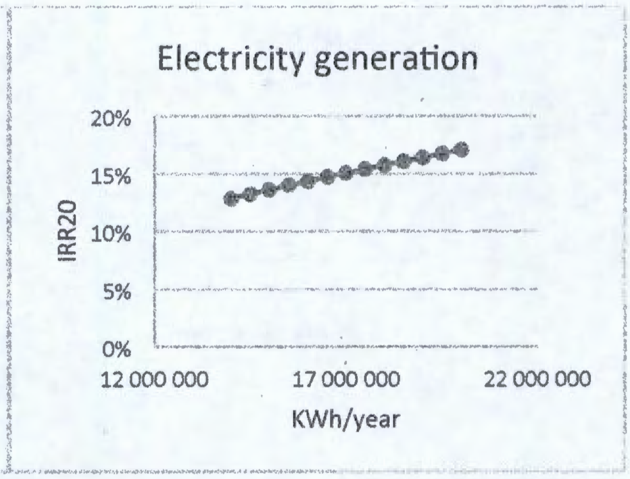

Electricity generation
IRR20
20%
15%
10%
5%
0%
4 000 000
9 000 000
14 000 000
KWh/year

10MW (P)


Capex


Electricty selling price


Gate fee


Electricity generation