Alternative electricity generation: Safripol as a case study

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Dissertation submitted in fulfilment of the requirements for the degree *Magister* in Development and Management Engineering at the Potchefstroom Campus of the North-West University

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November 2014

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Abstract

Electrical energy supply in South Africa, provided by ESKOM, has become more expensive with regular price increases in the past seven years. Increases on an annual basis have seen the Mega flex tariffs quadruple in the years from 2007 to 2014. ESKOM is the sole supplier of electricity to Safripol, a polymer producer of which the manufacturing facility is located in Sasolburg, South Africa.

This study will provide contextual information on what impact the escalation in cost of this utility has on the financial returns of the business. Independent power generation within the boundaries of the manufacturing site has become essential in order to alleviate the impact of inflated electricity costs, by at least 10% of the current total demand from ESKOM.

Primary research includes different types of alternative electricity generation techniques that will be able to deliver a practical solution to the business. The means of operation, required resources and cost to produce are set out to provide input into concrete models that are scaled to the potentials applicable to the production facility.

Total alternative electricity generation added up to almost half of the current total site electricity demand from ESKOM. This finding was truly beyond the expectations of the case study and clearly set out how understated the potential to generate electricity is within the industrial sector.

Keywords: Independent power generation, renewable energy, ESKOM tariff escalations, generation-potential, electrical power generation techniques, resources, requirements, sustained profit margins.

Acknowledgements

I would like to give special recognition to

- My wife, Miemie, who remains my sole supporter and ally in life, no matter what journey I embark on. The belief and support she provides are the very basis from which I can launch myself, to obtain accomplishments that I never imagined I would ever achieve.

- My two sons, Hugo and Zian, from whom I had to sacrifice a lot of personal time in order to complete this work, I can only add that I will make it up to them in due time.

- The management team of Safripol, for providing the opportunity and funds to enable me to complete my studies and further my skills and qualifications.

- Prof PW Stoker and Prof J Fick for hosting a very special and interesting Master's programme for the past two years. It has truly been a great learning experience and an enjoyable time indeed.

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List of Acronyms

AC	Alternating Current
AHEP	Annual Heat Energy Potential
Btu	British Thermal Units
CHP	Combined Heat and Power
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPI	Consumer Price Index
CPV	Concentrated Photo Voltaic
c-Si	Crystalline Silicon
DAWT	Diffuser Augmented Wind Turbine
DBMS	Database Management System
DC	Direct Current
DCF	Discounted Cash Flow
DMAIC	Define Measure Analyse Improve Control
DOE	U.S. Department of Energy
EEA	Electricity Engineers Association
EERE	Office of Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
EPIA	European Photovoltaic Industry Association
FGR	Flare Gas Recycle
GE	General Electric Corporation
GENSET	Power Generator or combination thereof
GJ	Giga Joule
GHG	Green House Gasses
GTI	Global Tilted Irradiance
h	Hour
HAWT	Horizontal Axis Wind Turbines
HDPE	High Density Polyethylene
HHV	Higher Heat Value

IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
J	Joule
kg	Kilogram
kW	kilo Watt
kWh	kilo Watt hour
l/s	Litres per Second
lbs	pound
LCD	Liquid Crystal Display
LCOE	Levelised Cost of Energy
LHV	Low Heat Value
LPG	Liquid Petroleum Gas
MAC	Maximum Asset Capacity
MMBtu	Million British Thermal Units
MSW	Municipal Solid Waste
MW	Mega Watt
NERSA	National Energy Regulator of South Africa
NHR	Net Heat Rate
NOx	Nitrogen Oxide
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
p.a.	Per Annum
PI	Profitability Index
PM	Particle Matter
PMA	Permanent Magnet Alternators
PP	Poly Propylene
PV	Photo Voltaic
RCSA	Regulation of Connecticut State Agencies
RCA	Regulatory Clearing Account
SARS	South African Revenue Service

Sox	Sulphur Oxide
TSA	Turbine Swept Area
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
V	Volt
VAWT	Vertical Axis Wind Turbine
VOC	Volatile Organic Compound
W	Watt
WACC	Weighted Average Cost of Capital
W_p	Watt peak power
WTE	Waste-to-Energy
ZAR	South African Rand

CHAPTER ONE

INTRODUCTION

1. Chapter One - Introduction

Safripol is a polymer manufacturing company, established in 1972, with its main production facilities situated in Sasolburg, South Africa. The company's sole purpose is to produce high-quality plastics, packed in granular form, to plastics distributors and converters.

The production plants possess a lot of opportunities to utilize the various types of kinetic and potential energy sources in order to supplement their electricity supply. This will reduce the company's dependence on ESKOM which is currently the sole provider of electricity to the production facility.

The two manufacturing plants within Safripol have expanded to their maximum capacities over the past 42 years. The current Maximum Asset Capability (MAC) of the facility will not be increased unless the possibility of an increase in monomer supply is realized. The electrical supply from ESKOM to the facility is also currently at its maximum capacity, unless new cable and transformer systems were to be procured and installed.

Safripol possesses ample opportunities to generate electricity by various methods, which if utilized in combination, could add to a significant improvement on the bottom-line for the business.

1.2. Problem statement

The rise in electricity costs stipulated by NERSA and approved by the Government of South Africa is expected to continue at a minimum rate of 8% per year (nominal) for the following 5 years (Official Newsletter of the National Energy Regulator of South Africa Volume VII, Edition II, 2013).

A rise in electrical utility costs, as provided by ESKOM, is directly linked to a reduction in profit margins within Safripol as a business.

The reduction of electricity usage by Safripol is not expected to be realized without a shortfall in production output from the facility. Independent power generation must be pursued in order to mitigate the effects of rising electricity costs.

1.3. Research aims and objectives

1.3.1. Research aims

The aim of the study is to present a solution to generate electrical power independent from ESKOM that will reduce the effect of rising electricity costs currently experienced from ESKOM as the sole electricity supplier.

The case study is focused on finding specific means of electricity generation using energy sources available in the manufacturing plant. Identifying which means of generation would be the most practical and also feasible for Safripol in order to generate at least 10% of the facility's total electrical demand, independently of ESKOM.

1.3.2. Research objective

Means of electricity generation investigated for the study included:

1. Solar Photo Voltaic (PV) electricity generation.
2. Excess hydrocarbon waste, utilized for combustion generation.
3. Kinetic energy harnessed to power turbine generators.
    a. Water-turbine generation
    b. Wind-turbine power generation.

The case study researched and presented the detailed requirements for each of the above-mentioned electricity generation techniques. Research into Safripol operations will be done in order to evaluate and identify the physical potential of the production facilities, which will lend it to satisfying the needs for alternative power generation.

The objective of this case study is to find the best possible solution in order to generate electrical power independent of ESKOM that will alleviate the effects of rising costs associated with this utility.

1.3.3. Research limitations

Means of electricity generation that were researched were limited to power generation-techniques, on an industrial scale, that were accessible at the time of this study. This study does not include the best practices, resources, means of power storage and requirements to connect autonomously produced power, to the national electrical grid.

1.4. Dissertation structure

This document consists of a number of chapters, all of which will briefly be discussed in this section.

CHAPTER 1

The first chapter functions as an introduction to the case study and provides a brief background of Safripol, as well as providing the research problem statement, objectives and limitations of the case study. A brief overview of the research study structure that was followed is also provided in this chapter.

CHAPTER 2

Chapter two presents the literature study underpinning each means of power generation. Research on the requirements and costing was done and the results were tabled to put each means of power generation in perspective with regard to total installed cost. Relation to all potential energy sources at the production facility at

Safripol was kept in mind, in order to focus the research study on the manufacturing site.

CHAPTER 3

The methodology used to conduct the practical research was designed, planned and concluded in this chapter. This chapter also reveals how to calculate the practical potential of the production facility in order to produce electricity. This chapter is used to present the generation methodologies presented in chapter 2, and then how to test the applicability and feasibility of the power generation techniques.

CHAPTER 4

This chapter was used to present the ways in which the execution of the empirical investigation took place for each of the power generation methodologies. All the practical findings are tabled in accordance to capacity and required total capital investment. Electrical tariffs applicable to each means of power generation are determined to provide input into the financial models. Internal rate of return, net present value of cash flow and profitability index for each means of power generation technique were the financial deliverables from this chapter.

CHAPTER 5

Various findings from chapter four on all the alternative means of power generation are discussed. The importance of social responsibility of Safripol as a business is brought into the models to add different angles of approach to the possible power generation alternative. The results presented here lead to concluded findings as to which means of power generation has the biggest potential and is the most financially feasible to Safripol.

CHAPTER 6

The penultimate chapter provides the best recommendation to the business with regard to the best possible combination of power-generation procedures. The conclusion and other recommendations from this case study are presented. Other topics for further study are listed and elaborated on.

1.5. Chapter one - closure

Chapter one provided the introduction to this case study. The background of Safripol's dependence on ESKOM was elaborated on, clearly identifying the need for the facility to generate a portion of its required electrical power, due to price increases that are set to continue for at least the next five years. The next chapter provides the literature study to enable the reader to develop an understanding of the requirements and resources needed in order to embark on independent power production.

CHAPTER TWO
LITERATURE REVIEW

2.1. Chapter Two - Introduction

This chapter provides background to Safripol as a production facility, and also gives some view of what power generation possibilities it may provide. The literature review was conducted on the four types of power generation as set out in the objectives in chapter one namely:

- Solar Photo Voltaic (PV) electricity generation.
- Excess hydrocarbon waste, utilized for incineration and internal combustion generation.
- Kinetic energy harnessed to power turbine generators.
    - Water-turbine generation
    - Wind-turbine power generation

The means of operation, resource requirements and the cost to produce electricity are clearly presented for each of the means of power generation. The possible connection to Safripol production processes is linked to the type of power generation. This is presented in order to understand the connection between the possibility that Safripol provides and the requirements that the means of power generation would demand.

2.2. Background to the facility - Safripol

The two main types of plastics manufactured by Safripol are; Poly Propylene (PP) and High Density Polyethylene (HDPE). The production facility is situated in Sasolburg, which a town in the northern Free State Province.

The production plants manufacture polymers (HDPE & PP) from two main types of monomers which are ethylene and propylene. Other raw materials such as butane, pentene, hydrogen, catalyst and activator also form part of the ingredients needed in the chemical processes. These ingredients are accurately mixed according to recipes and specific process conditions, to react in chemical reactors in order to manufacture the polymers.

Utilities such as steam, nitrogen and compressed air are extensively used throughout the drying sections of the production plants. Cooling water systems are used to control the temperature inside the chemical reactors to ensure that the polymer produced is done according to strict recipe conditions.

The production plant's design is done in order to minimize effluent and any other form of gas emissions from the processes. All the water cooling and nitrogen drying systems are in the form of closed-loop piped systems, which ensures that utility consumption is kept to the minimum. The drying systems (mainly done with heated air systems) on the HDPE production plant is done with an open-ended design, the used air being emitted back to the atmosphere through filtered exhaust systems.

Produced polymer is then packaged and stored on wooden pallets in a warehouse that has a capacity of 30 kilo tons and which covers a total ground area of 39 000 m². The requirement of such a large warehouse is due to the large number of different grades of plastics produced and a need to fill orders in a niche market.

2.3. Solar Photo voltaic (PV) electricity generation

2.3.1. Introduction to Solar PV

Solar cells used to generate electricity are also called photovoltaic (PV) cells, convert sunlight that is absorbed onto the PV cell directly into electricity. PV gets its name from the process of converting light energy (photons) to electrical energy (voltage), which in turn is called the *PV effect*.

Photovoltaic energy was first discovered by Becquerel in 1839, when he noticed that certain light-induced chemical reactions caused electrical currents to flow. Since then a lot of research has been conducted and as soon as the first silicon solar cell was developed by Chapin, Fuller and Pearson in 1954, a new viable electricity generator was born. This technology involves no moving parts and operation and maintenance costs are low in comparison to other forms of power generation. (EERE Energy, 2010)

2.3.2. Means of operation

2.3.2.1. Photovoltaic effect

Using an N-type and a P-type semi-conductor in combination can produce an electrical current when electrons are absorbed through sunlight that is shone on the junction of the two semi-conductors. Extra electrons that are absorbed from sunlight will cause an excess of electrons in the N-type semiconductor and they will try to move from the N-type semiconductor through the crystalline mesh (junction) to the P-type Semi-conductor which is ready to accept the electrons (Solareis, 2010).

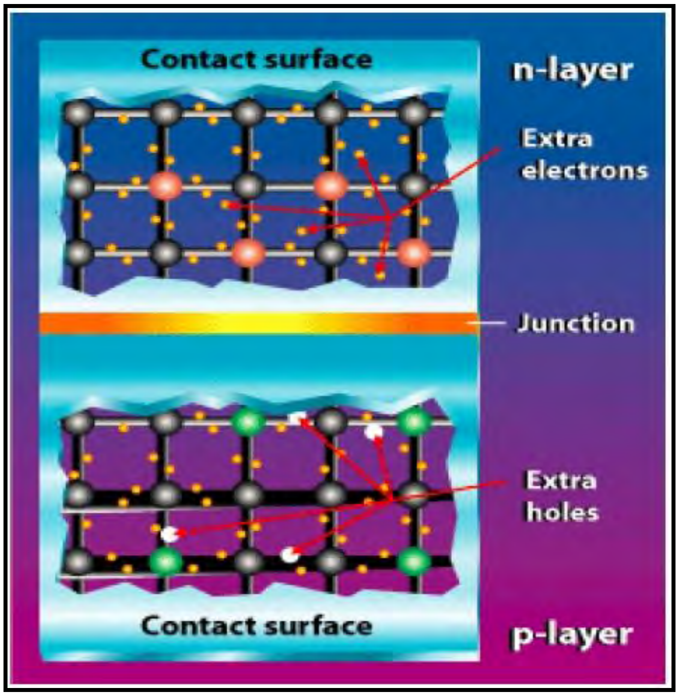


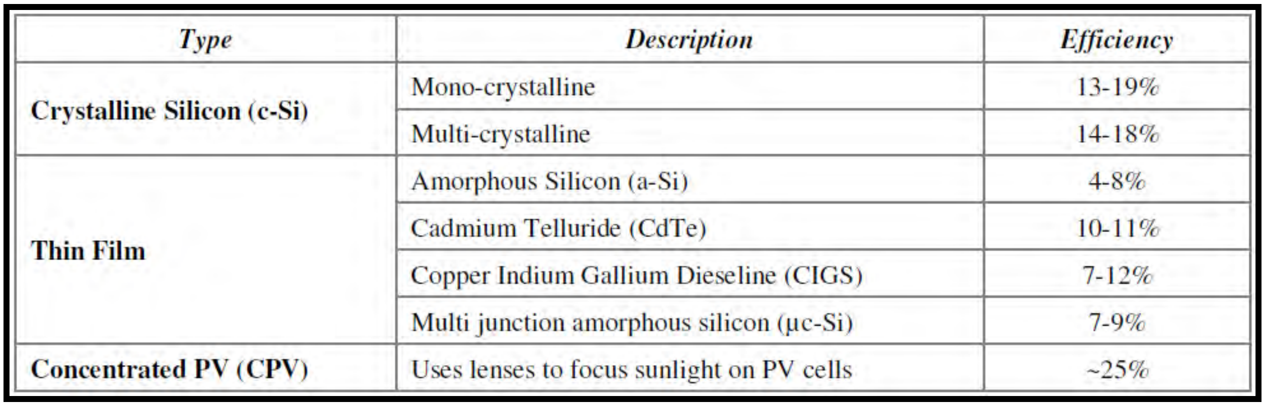
Figure 2.1: N-Type & P-Type combination (source: EERE Energy, 2010)

The electron deficiency (hole) in the P-Type semi-conductor will be filled with electrons as soon as a load is connected to the connectors of the semiconductor combination. The figure below illustrates the combination of semiconductors as well as the holes that will be filled with extra electrons.

A number of materials can be used to create semiconductors which are used in manufacturing solar cells, they include:

- Crystalline Silicon
- Copper Indium Gallium Dieseline
- Cadmium Telluride
- Gallium Indium Phosphide
- Amorphous Silicon

Each of the materials of the technologies used in the manufacturing process will lead to differentiated efficiencies, as can be seen in the table below (Solareis, 2010).



Type	*Description*	*Efficiency*
Crystalline Silicon (c-Si)	Mono-crystalline	13-19%
	Multi-crystalline	14-18%
Thin Film	Amorphous Silicon (a-Si)	4-8%
	Cadmium Telluride (CdTe)	10-11%
	Copper Indium Gallium Dieseline (CIGS)	7-12%
	Multi junction amorphous silicon (μc-Si)	7-9%
Concentrated PV (CPV)	Uses lenses to focus sunlight on PV cells	~25%

Table 2.1: Cell efficiencies per material of construction (source: SAPVIA, 2013)

The correct semiconductor material needs to be selected, in order to ensure that the efficiency of the semiconductor is kept to a maximum. The degree of crystallinity controls the sunlight-to-electricity conversion effectiveness.

2.3.2.2. Fabrication of solar panels

Solar PV panels have inherent energy losses which range from:

- System losses; which include losses in electrical wiring, the inverter system and transformers.
- Thermal and module losses; efficiency that is related to the temperature influences that impact on the solar module.
- Pre-photovoltaic losses; diminution of incoming light due to dirt, shadowing and reflection of sunlight before it hits the PV cell.

It is therefore important to keep these losses in mind when manufacturing the panels in order to mitigate the losses as stated above. The manufacturing process can thus address the potential losses by:

- Improving the physical layout of the PV module and its frame.
- Alleviating reflection from the encapsulating glass, covering it with an anti-reflective coating or sheet.

- Minimizing series resistance losses from connections (Buemi et al., 2013).

Figure 2.2 (below) illustrates the physical module frame layout in the manufacturing phase.

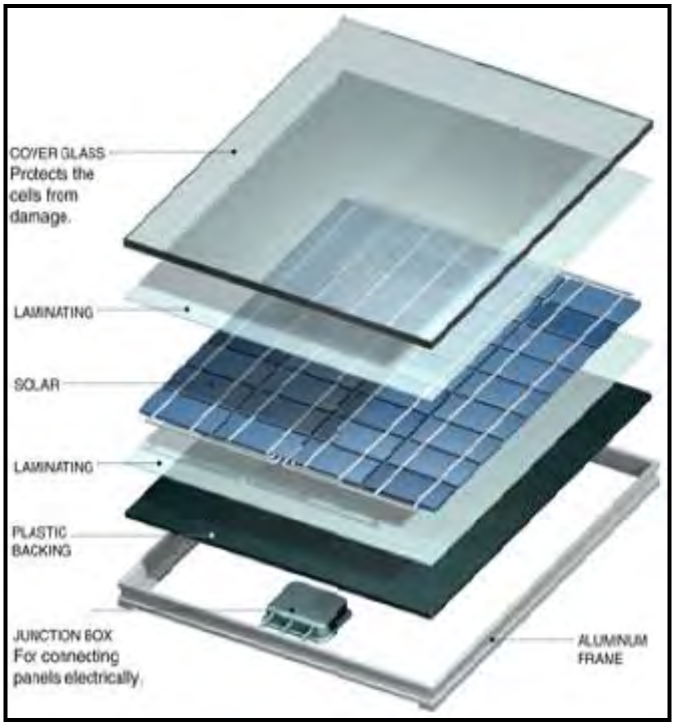


Figure 2.2: The physical layout of a PV module (courtesy of Buemi - Understanding Photovoltaic Cell and Module Level Efficiency, 2013)

The PV panels can be arranged from a single PV cell which can be used to power small electronic devices which deliver approximately 0.5 Volt. Cells can be arranged in series to complete a module, which can power larger devices. Modules can be connected in series and/or parallel to form an array, which are used to power ever larger loads.

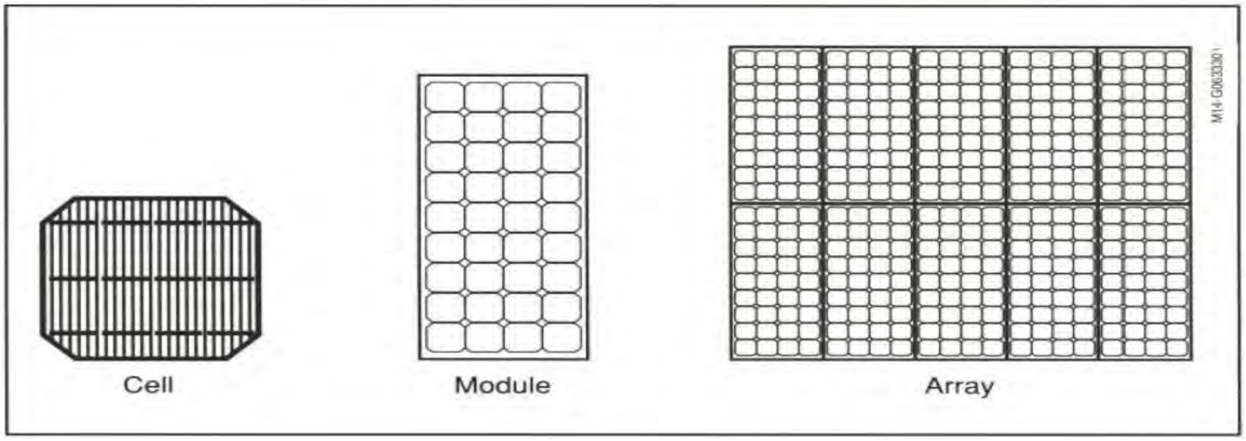


Figure 2.3: PV Cell arrangement (courtesy of Earthsci.org, 2011)

2.3.2.3. Large-scale photovoltaic system

A typical Photovoltaic system is made up from several key components, including:

- PV modules
- Inverter
- Transformer
- Monitoring meter
- Balance-of-system components.

These components are then organized to accordingly and connected to the utility grid as can be seen in figure 2.4, in order to supply the user with PV generated electricity (Simon & Mosey et al., Jan 2013).

a) PV Module

PV module technologies are distinguished by the type of PV material used, which results in a range of conversion efficiencies from light energy to electrical energy. The PV module efficiency is a measure of the percentage of solar energy converted into electricity. The two common PV technologies that have been widely used for utility and commercial-scale projects are thin film and crystalline silicon.

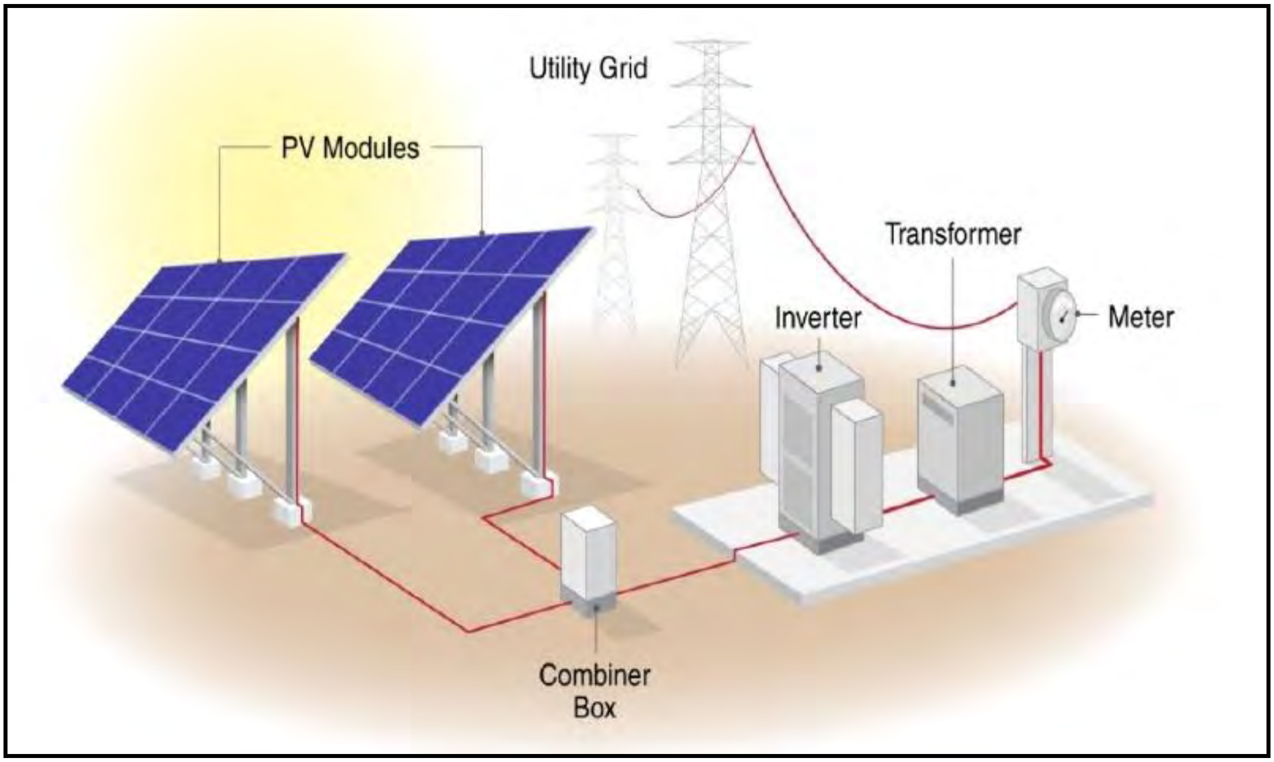


Figure 2.4: Ground mounted array diagram (source: NREL, 2012)

b) Inverter

Inverters are used to convert Direct Current (DC) electricity from the PV array into Alternating Current (AC) electricity and can connect seamlessly to an electrical utility grid. Inverter efficiencies vary from manufacturer and design, but can be as high as 98.5% (Simon & Mosey et al., Jan 2013).

Inverters furthermore sense the utility power frequency and then synchronize the PV-produced power to the frequency of the grid it is to be connected to. When utility power is not present due to equipment failure, the inverter will stop producing AC power to prevent "islanding" or putting power into the electrical grid while maintenance is being conducted on the de-energized distribution system. This is a safety feature that is built into all grid-connected inverters in use in the market. There are two major types of inverters for grid-connected systems:

- String and
- Micro-inverters.

String inverters are the used in most applications and they typically range in size from 1.5 kW to 1,000 kW. These inverters are likely to be more cost-effective on a capacity basis, as fewer units are needed to serve a higher supply of electrical power. String inverters have high efficiency and lower operational and maintenance costs. On larger PV systems, string inverters are connected in parallel to ensure a single point of interconnection with the utility grid.

Micro-inverters are dedicated to the conversion of a single PV module's power output. Current micro-inverters range in size between 175 W and 380 W. These inverters are typically a more expensive option per watt of capacity than string inverters.

With string inverters, small amounts of shading on a solar panel will significantly affect the entire array production. Instead, it impacts only that shaded panel if micro-inverters are used. (Simon & Mosey et al., Jan 2013).

Inverters can be combined with control circuits that extract the maximum potential even from individual shaded panels. The following example explains this functionality.

Take a system that typically consists of ten modules that are connected to an inverter. Module number three is only receiving 80% of the light compared to the other modules in its string. The current flowing through all modules in this string is equal (serial connection) therefore the centralized inverter will do one of the following control options:

i. To continue working at the maximum power point of all ten modules, while activating the bypass diode in module three. The total power produced by the system will then add up to be: 9x10% + 1x6.6%= 96.6%
ii. The controller will reduce the total current on the system to 80% that will ensure that the bypass diode on panel number three is not activated. The total power from this system will then be : (10x80%) ÷10 = 80%

iii. Utilizing individual power point tracking the controller can isolate module three, only allowing 80% of the current to flow through it. Therefore the system power will be: {(9x100%) + (1x80%)} ÷ 10 = 98% (solar Edge, Aug 2010)

c) Transformer

Electricity produced from the PV system can then be fed to a step-up transformer to increase the voltage to match the required voltage of the grid. This function is important when designing a PV system that need to supply a utility grid for large scale use.

d) Monitoring meter

Monitoring of PV systems is essential for reliable functioning and ensuring maximum yield of a PV system. It can provide reading values such as:

- Produced AC power ;
- Daily kilowatt-hours; and
- Cumulative kilowatt-hours.

This can be recorded and displayed locally on an LCD interface on the inverter panel. Other important variables can be monitored and connected to the monitoring module. The data can also be recorded in the monitoring meter’s memory system which can be used for system analysis. These variables can include:

- module temperature;
- ambient temperature;
- solar radiation; and
- wind speed.

The Monitoring System can then send alerts and status messages to the user control centre (Simon & Mosey et al, Jan 2013).

2.3.2.4. Installation considerations

It is important to take note that PV modules are very sensitive to shading or partial shading that may be induced on the PV modules. When partially or fully shaded, the PV panel will not be able to optimally collect the high-energy beam radiation from the sun.

As explained above, PV modules consist of many individually connected PV cells which collectively produce a small amount of current and voltage. These individual cells are connected in series to produce a larger current. If any individual PV cell is shaded, it acts as resistance to the whole series PV circuit, obstructing current flow which will dissipate power rather than producing it.

Irradiance is defined as "*The density of radiation incident on a given surface usually expressed in watts per square centimeter or square meter (W/m^2)*" – Merriam Webster (Encyclopaedia Britannica)

Optimum angle refers to the angle at which PV modules should be oriented in order to generate maximum electricity by capturing the maximum irradiance at an angle of ninety degrees to the sun. The main parameter influencing optimum angle is latitude. It is important to ensure that the array is installed at the correct tilt angle to ensure that the maximum amount of radiated energy from the sun is captured.

As a general guideline, photovoltaic solar panels should be mounted at an angle of ten to fifteen degrees plus the site's latitude. Therefore in Sasolburg, where the latitude is set at around 26 degrees south, solar PV panels should ideally be mounted at a tilt angle of approximately 36 to 41 degrees facing north.

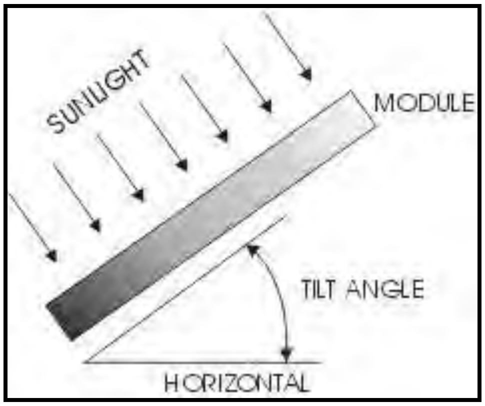


Figure 2.5: PV module tilt angle (courtesy of REUK U.K., 2014)

Global Tilted Irradiance/Irradiation (GTI) is the total irradiation from the sun that falls on a tilted collective surface. GTI is an important parameter for PV system designers. PV modules are installed on different mounting systems, such as:

- Fixed tilted construction - which is the least effective but, consumes the least amount of land space.
- One-Axis tracking – this type of mounting is more effective but, consumes more land space in order to allow the angular movement.
- 2-axis tracking and their variations (see some examples on the image below) – This type of mounting is the most effective as it allow for angular and lateral rotation to follow the sun but, consumes the most land space.

For each particular mounting system, GTI is calculated individually and can play a major role in order to ensure that the mounting method is seizing the best efficiency from the PV module or array system (Solargis, 2012).

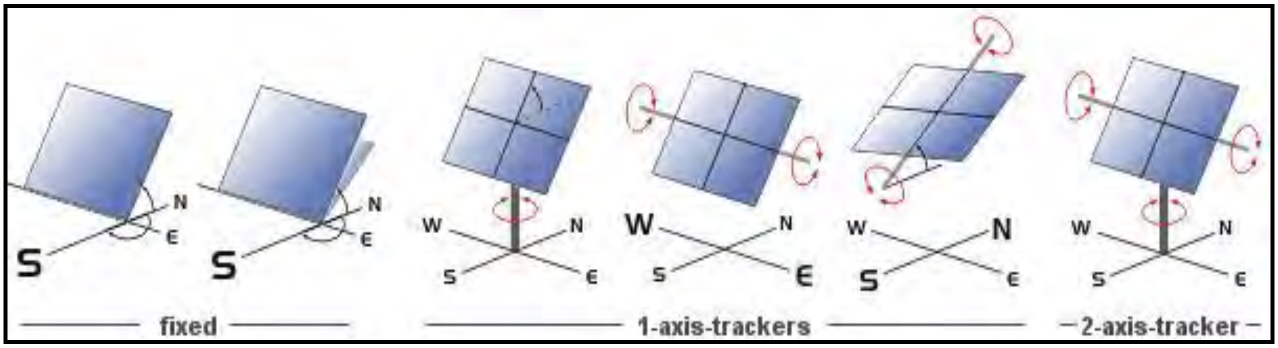
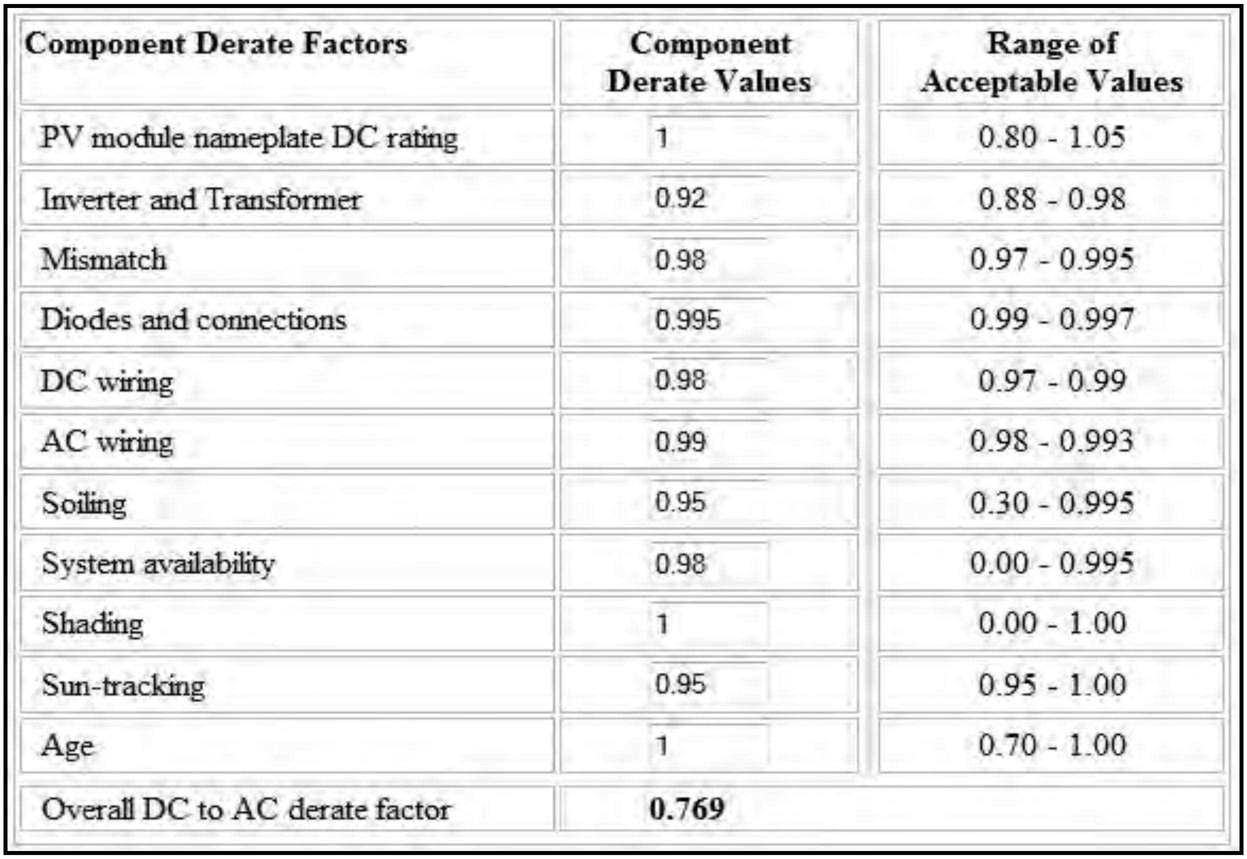


Figure 2.6: Tilted angles for PV Module installation (courtesy of Solargis, 2012)

Careful consideration should be given to the structural integrity and condition of buildings according to their designs, should the PV array be mounted on an existing roof. Inspect the roofs for abnormalities, sag and depression which would indicate that the structure may not be able to support the dead loads resulting from a PV array system (Solargis, 2012).

The total system in-efficiencies will in combination add up to a total system power loss. This loss is called a De-rate factor that can be used to calculate the system efficiency in total which needs to be taken into consideration when sizing PV generation systems. Table 2.2 is an example of a typical Solar PV system's calculated De-rate factor.



Component Derate Factors	Component Derate Values	Range of Acceptable Values
PV module nameplate DC rating	1	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System availability	0.98	0.00 - 0.995
Shading	1	0.00 - 1.00
Sun-tracking	0.95	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC to AC derate factor	**0.769**	

Table 2.2: Total PV system De-rate factor (courtesy of NREL, 2014)

2.3.3. Resource requirements

2.3.3.1. Sunlight

Solar energy refers to energy derived from the sun or sunlight. It is therefore imperative that the geographical site selection be made in order to capture the maximum amount of sunlight possible.

It may be the case to accept that South Africa in general is well situated to provide good exposure to sunlight, but not all of the country is exposed to such high levels of sunlight energy. Many of the coastal areas as well as some of the Southern and Eastern parts of South Africa are not so well situated to provide long lasting and intense sunlight.

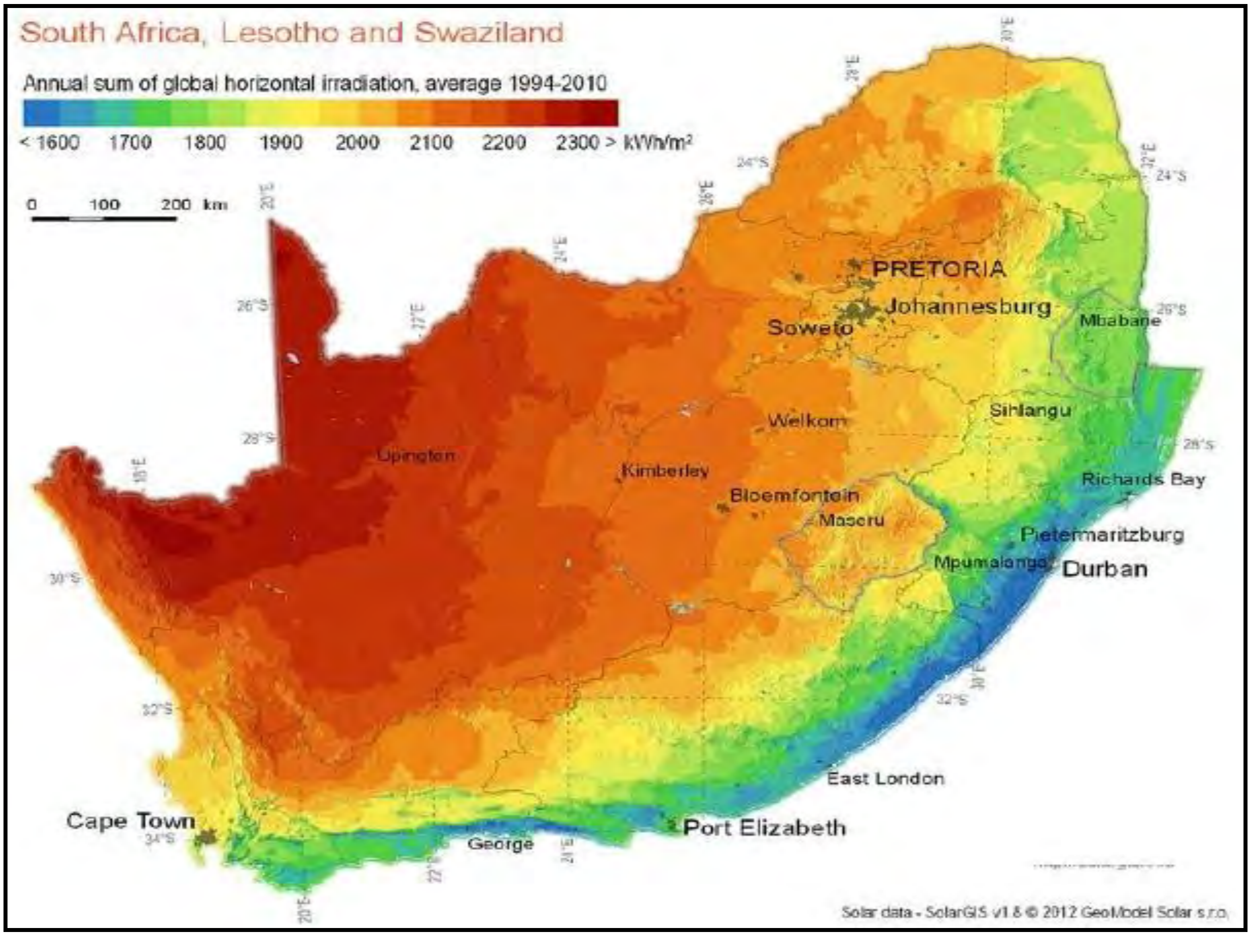


Figure 2.7: Horizontal irradiation South Africa (source: SOLARGIS, 2014)

Figure 2.7 clearly indicates the best areas to locate solar array plants, which are mostly situated in the North-Western parts of South Africa. These areas have an average of 2300 kWh/m^2 irradiation for the years 1994 to 2010.Germany is typically exposed to an average of 1100 kWh/m^2 (Solargis, 2013), and they are currently the biggest users of solar PV panels, producing 35.7 GW of electricity (IEA-PVPS, 2013).

Fortunately South Africa is one of the countries worldwide that has a good amount of sunlight exposure. This means in general that the country makes for a preferred location to install Solar PV plants. This just emphasizes the fact that most of South Africa, which is exposed to an average of 2000 kWh/m^2 of irradiance, can exploit solar PV energy at almost twice the efficiency that Germany is currently experiencing (Meyer et al, 2013).

In figure 2.8 we can see that South Africa is one of the preferred destinations to embark on generating power from PV technology. Countries in the graph illustrate the overall investment attractiveness versus the PV attractiveness of a country due to its irradiance levels and Solar PV policies (EPIA, 2013).

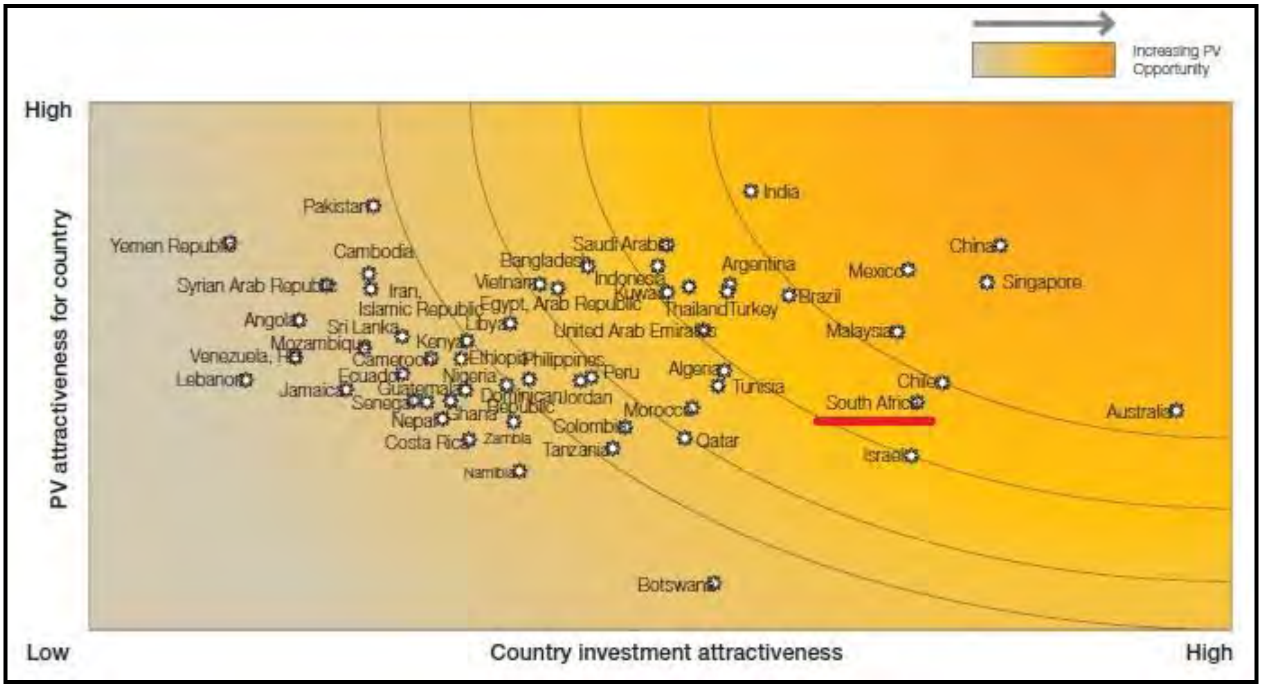


Figure 2.8: PV investment attractiveness per country (courtesy of EPIA.org, 2013)

2.3.3.2. Land space

Land space requirements are an important aspect with regard to PV installations. The more space you have available, the more PV panels you can install. This means that there is a direct relation between the amounts of power that can be generated versus the amount of land space that you have available.

An advantage of PV power generation is that should you have available building infrastructure in place, because then you can utilize the roof areas instead of sacrificing valuable ground space. Land area is divided into 2 categories namely:

- Total area

- Direct area

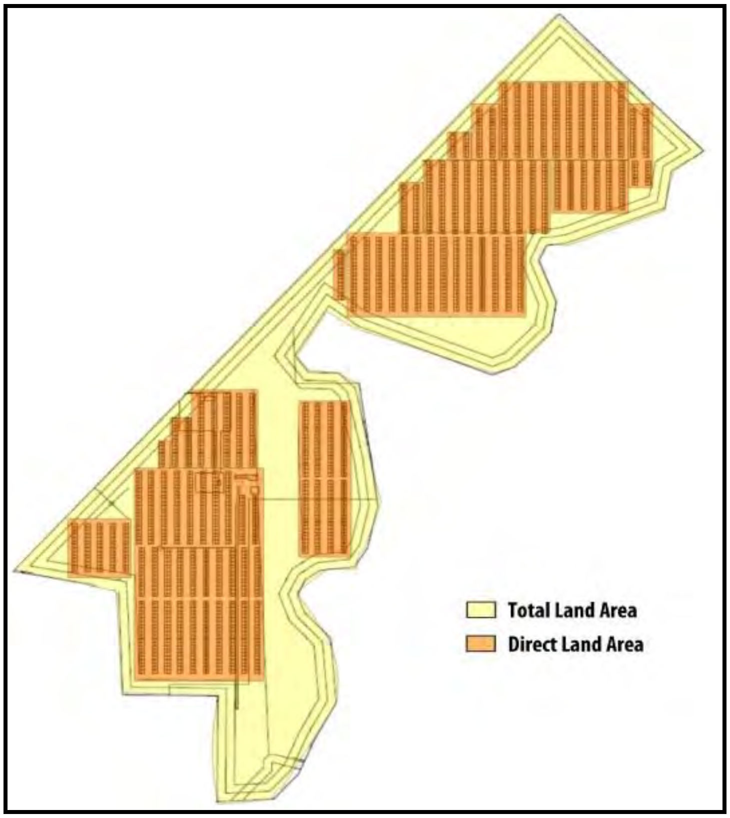


Figure 2.9: Total land area vs direct land area (courtesy of NREL, 2012)

Total area refers to the total area covered by a typical solar farm, from fence to fence. Direct area refers to the physical space that the PV panels and ancillaries consume within the fenced area. Figure 2.9 gives a graphic explanation of this.

In the table below land use results from different projects (all installed in the state of California, USA) with different module efficiencies are shown. Included are calculations which indicate the relationship between power produced and the amount of land space required in Hectares. From the table it is clear that for the 6 PV solar plants, the average power production is set at 0.34 MW per 1 hectare of total land space. It is also clear that the lower the efficiency of the modules installed, the larger the amount of land space that is required will be in order to generate the same amount of electricity (Ong, Campbell, Denholm, Margolis, & Heath et al., 2013).

Solar Plant Name	State	MW - DC	Total area (acres)	Total area (hectares)	Direct area (acres)	Module efficiency	Status as of August 2012	Hectare per 1 MW DC	MW DC Power per Hectare
Sacramento Soleil	CA	1.3	10.0	4.0	8.1	11%	Complete	3.11	0.32
USMC 29 Palms	CA	1.3	10.6	4.3	7.0		Complete	3.30	0.30
Box Canyon Camp Pendleton	CA	1.4	9.6	3.9	5.6	14%	Complete	2.78	0.36
Vaca-Dixon Solar Station	CA	2.6	17.8	7.2	11.5	14%	Complete	2.77	0.36
CALRENEW-1	CA	6.2	60.4	24.4	46.5	9%	Complete	3.94	0.25
Porterville Solar Plant	CA	6.8	37.6	15.2	31.4	14%	Complete	2.24	0.45
							Average:	**3.02**	**0.34**

Table 2.3: PV Land use data (courtesy of NREL, 2012)

The physical size of PV panels differs from manufacturer and also the type of material used to produce the PV crystals. Typical panel sizes for 250W Mono-crystalline panels will consume ± 1.6m^2 per PV panel (see figure 3.1, KSolar PV panel specifications).

2.3.4. Cost to produce

The costs to manufacture PV panel have decreased considerably since 1991. The manufacturing cost of PV systems in Europe has decreased by 50% (EPIA, 2011) from 2006 to 2011, which was also the trend in the USA. It can be seen in Figure 2.10 that the manufacturing cost of PV panels has been reduced from \$5.70 $W_p/\$$ in 1992 to a low of \$0.65 $W_p/\$$ in 2012 (Mints et al., 2013).

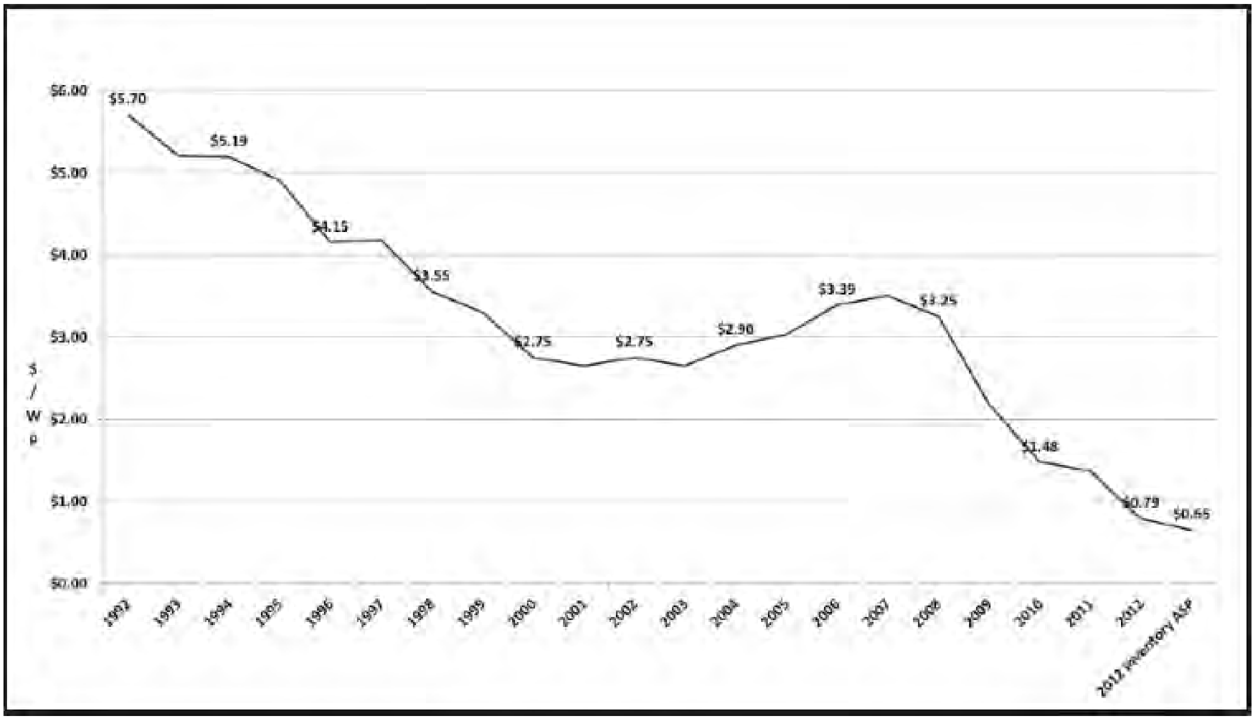


Figure 2.10: Cost of PV panels (courtesy: Mints. P, 2013)

There are various reasons for this decline in manufacturing costs and this can be mainly attributed to:

- A great increase in global demand for PV panels;
- Manufacturing technologies that have been improved;
- Larger demand quantities which to large-scale production assemblies.

The major costing that contributes to the PV system can be divided into the following components:

- The PV modules;
- Inverter;
- Mounting hardware and support structures;
- Wiring and cable costs;
- Batteries;
- Controller or monitor; and
- Other unaccounted extras such as labour (Maphelele & Stanford et al., 2013).

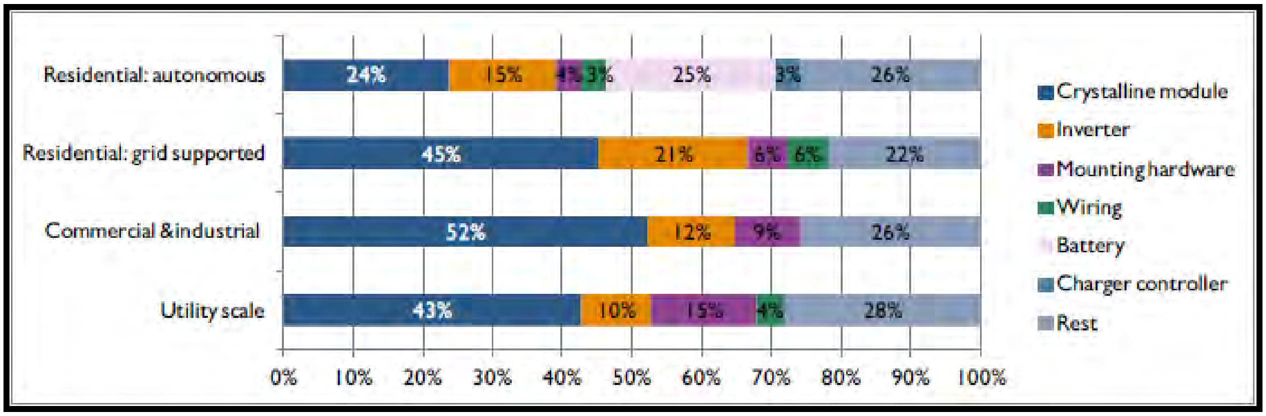
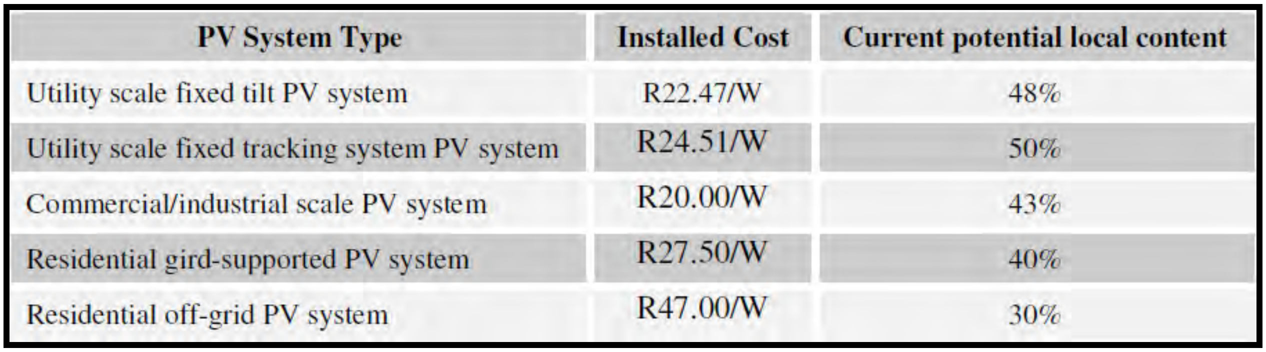


Figure 2.11: PV system cost breakdown (source: EScience, 2013)

It is clear that the PV panel cost has the biggest influence on the PV system total cost in almost all four configurations. In figure 2.10 we can see that the cost of PV panels has been reduced dramatically over the past decade. It is then easy to understand that the total system cost as well as the cost to produce PV electricity has dropped accordingly.

The table below gives an indication of what the installation of a typical PV power system would cost in 2013 (Ahlfeldt et al, Mar 2013).



PV System Type	Installed Cost	Current potential local content
Utility scale fixed tilt PV system	R22.47/W	48%
Utility scale fixed tracking system PV system	R24.51/W	50%
Commercial/industrial scale PV system	R20.00/W	43%
Residential gird-supported PV system	R27.50/W	40%
Residential off-grid PV system	R47.00/W	30%

Table 2.4: Costs for PV systems - installed (source: EScience, 2013)

The maintenance costs include the periodic cleaning of the panels and disposal or rehabilitation of water used. This is calculated to be around 0.84% of the initial system cost on an annual basis.

Additional costing benefits include carbon tax deductions which are set at a nominal rate of R120/ton, which is deemed to be implementable as from 2016. During the initial phase (2016 to 2019) only 40% of the emissions will be taxed but, the rate is set to be increased at 10% per annum until 2019. The generation of electricity from renewable sources will allow a company to deduct the carbon savings from their total emission report sheet. This will allow for reduced CO taxes to be paid to the revenue service.

The complete framework and conditions, however, have not been finalized and the Carbon Offset Scheme is planned to come into effect in 2016. Costs benefits in relation to carbon offsets can thus not be included for 2015 as a savings but will have a positive influence on the costing structures for future projects from 2016 onwards (Dept. of Energy, Nov 2013).

2.4. Electricity generation from hydrocarbon waste with the use of rotating generators

2.4.1. Introduction

The industrial sector provides abundant opportunity to utilize waste energy to be re-used for power generation. Waste energy needs to be clearly understood and therefore the definition as stated by the United Nations Framework Convention on Climate Change (UNFCCC) is stated in the paragraph below.

Waste Energy: "*Energy contained in a residual stream from industrial processes in the form of heat, chemical energy or pressure, for which it can be demonstrated that it would have been wasted in the absence of the project activity. Examples of waste energy include the energy contained in gases flared or released into the atmosphere, the heat or pressure from a residual stream not recovered (i.e. wasted)"* (UNFCCC et al., Appendix 5: Page 3/60, ACM0012, 2012).

The above-mentioned definition states that there are various forms of waste energy which include:

- Chemical energy;
- Heat; and

- Pressure.

In this section have investigated the means of power generation by recovering wasted hydrocarbons (chemical energy), and then using this as a fuel for power generation by making use of steam or carbon-based fuels for reciprocating engine-driven generators. For the purposes of this study we will discuss the means of generating fuel or steam to drive rotating generators but, the study has not provided details around the design of steam turbines or reciprocating engines.

2.4.2. Converting hydrocarbon waste into energy

Converting waste materials that are deemed to be disposed of to municipal waste streams into electrical energy is called Waste-to-Energy (WTE). This process includes the burning or gasification of Municipal Solid Waste (MSW) in order to extract fuel (either steam or hydrocarbon fuel to drive rotating generators. There are several processes that can be followed in order to convert MSW into fuel sources and figure 2.12 gives an illustration as to the most popular means to achieve this.

The Plasma gasification, Biochemical and Pyrolysis processes will be omitted for this case study due to the high initial capital cost included in establishing these plants. The cost-effectiveness for these units is particularly good when larger units are built, but this is not applicable to the case at Safripol.

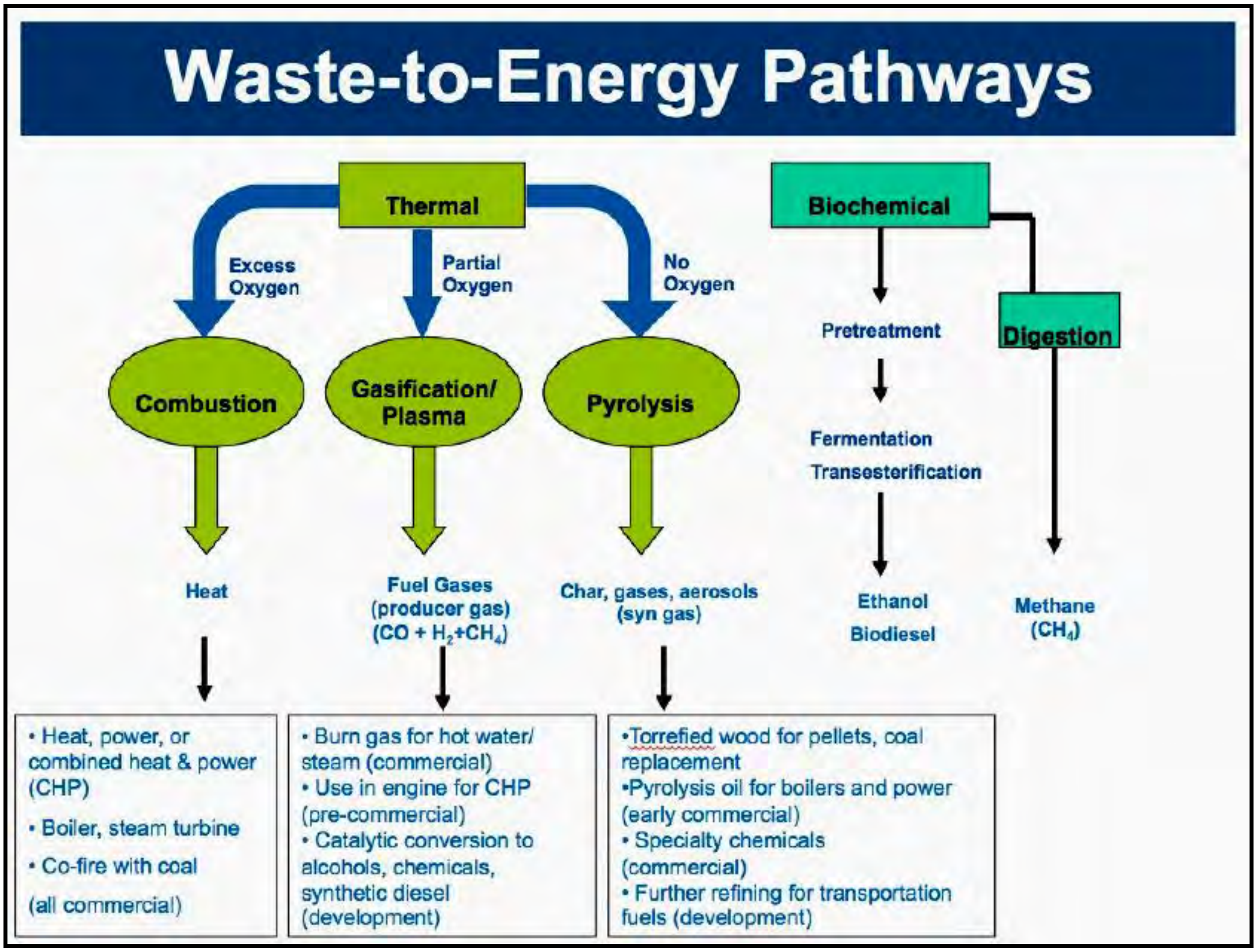


Figure 2.12: Waste to energy pathways (courtesy of NREL, 2013)

2.4.3. Steam turbine-driven generators

Combustion processes (or boilers) are used to create heat energy with the aid of incinerators which burn hydrocarbon-based waste materials in order to produce steam. Steam is the medium used to drive steam turbines which are then used to turn electrical generators. Steam turbines operate separately from the rest of the waste-combustion process and allow for the re-capturing of the water used in the steam process in order to operate as a closed loop.

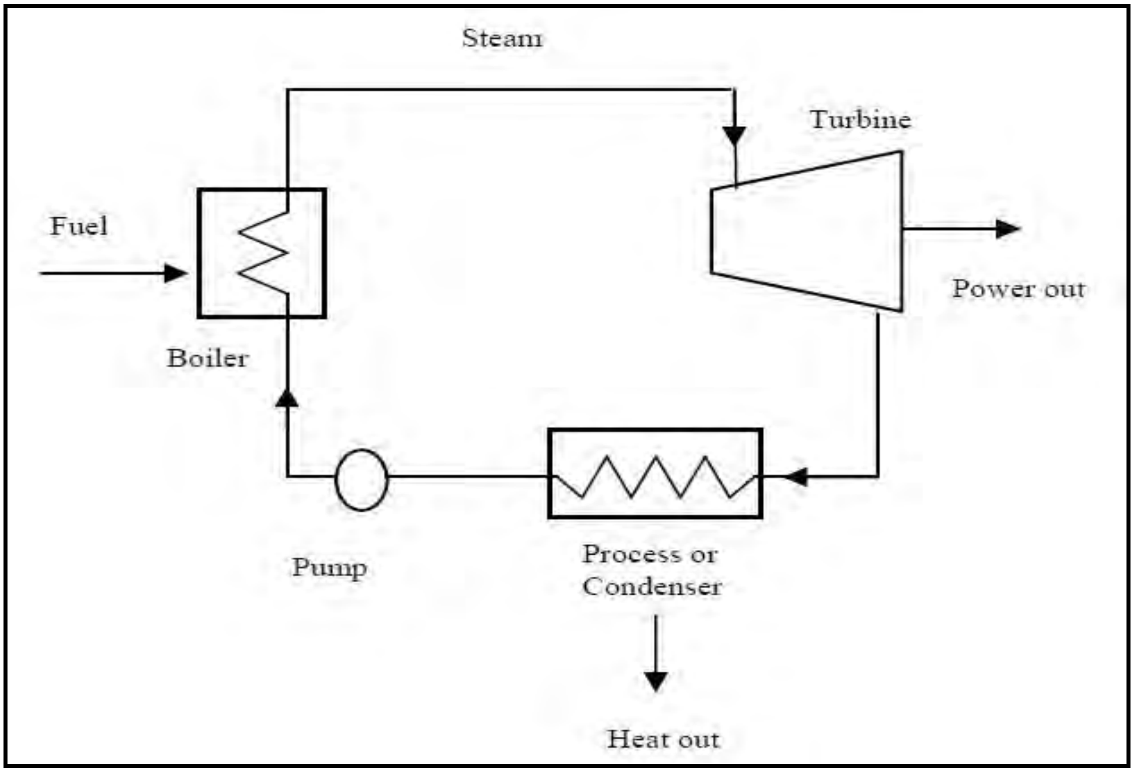


Figure 2.13: Components of a boiler/steam turbine system (courtesy of EPA, Technology Characterization: Steam Turbines)

Steam-driven generators can be sized according to the availability and physical properties of the steam to be used. Small-scale steam-driven generators can be sized even as low as 15 kW. *Green Turbine BV* is a manufacturing company that specializes in manufacturing such micro-scale steam turbine generators. These units will operate on steam with temperatures as low as 200°C at 12 Bar G.

Figure 2.14: Green turbine 15kW (courtesy of Green Turbine BV, 2014)

Steam turbines can be used to convert superheated steam into saturated steam by means of directing the steam onto the turbine rotors through nozzles. The turbines consist of a number of stages of which each stage output will act as the input to the next stage of the turbine. As the steam loses energy (momentum) through the stages it will also loose temperature and pressure, causing the steam to become saturated (Spirax Sarco, 2014, *Principles in steam engineering*).

2.4.3.1. Efficiencies of steam-driven turbines

The thermodynamic efficiency of steam turbines can be determined by applying one of the following theories:

- The Rankine Cycle – the delta in heat energy of the steam between the inlet and outlet of the turbine, compared with the total energy taken from the steam.
- The Carnot Cycle – the delta in temperature between inlet and outlet of the turbine, compared to the inlet temperature of the steam (Spirax Sarco, 2014, *Principles in steam engineering*).

Electrical efficiencies of steam-driven turbine electrical generator units vary from 36% Higher Heat Value (HHV) large generation facilities to as low as 10% for smaller plants that utilize excess heat as an input. The smaller plants can tolerate such low efficiencies due to the fact that the heat would have been wasted.

Small single-stage turbines used in the industrial size units can have efficiencies as low as 50%. Multi-stage high pressure ratio units' thermodynamic efficiencies can vary from 65% (typical units under 1 MW) to as high as 90% for the utility sized units (EPA, Technology Characterization: Steam Turbines, 2008).

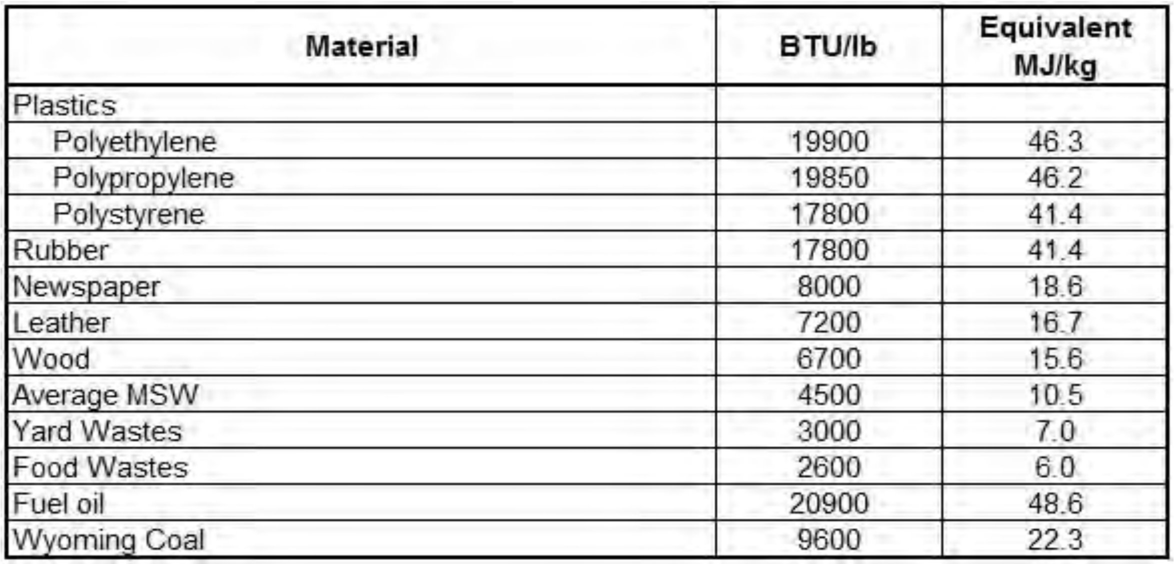
2.4.3.2. Min fuel requirements

The effectiveness of the combustion inside the incinerators is greatly influenced by the moisture content and also the potential heat energy of the fuel burned. This potential is measured in British Thermal Units (BTU's) which act as the yardstick in selecting the best possible fuels for the incineration or gasification process.

Industrial boilers operate on a variety of fuels which includes:

- Wood (solid or chips);
- Coal;
- Natural gas;
- Oils (including waste lubricants);
- Municipal solid wastes; and
- Other hydrocarbon rich materials (plastics or rubbers).

Fuel handling, preparation and storage add to the total cost of the installation and need to be catered for. Table 2.5 includes some of the prevalent MSW materials as well as their BTU values.



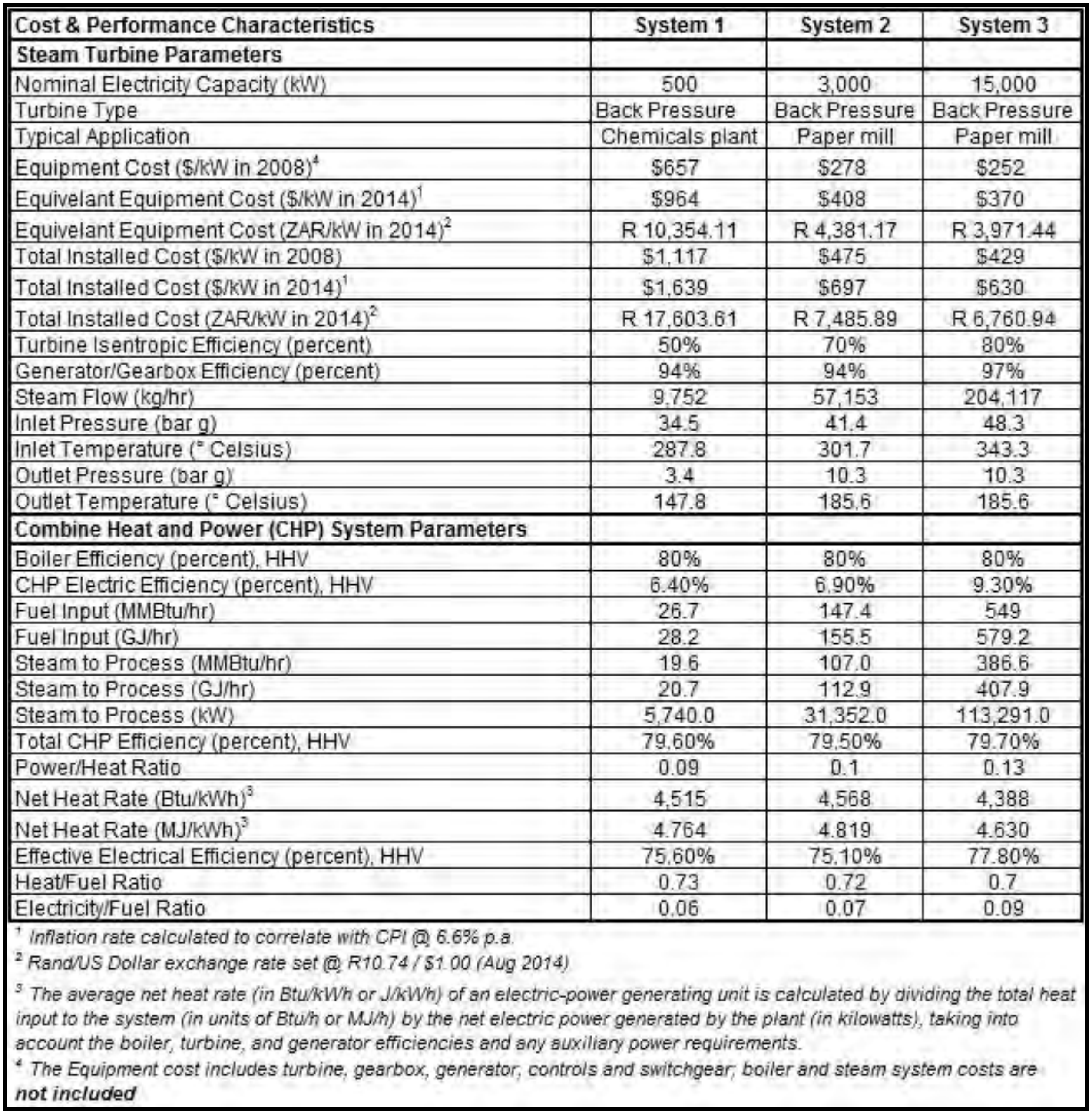
Material	BTU/lb	Equivalent MJ/kg
Plastics		
Polyethylene	19900	46.3
Polypropylene	19850	46.2
Polystyrene	17800	41.4
Rubber	17800	41.4
Newspaper	8000	18.6
Leather	7200	16.7
Wood	6700	15.6
Average MSW	4500	10.5
Yard Wastes	3000	7.0
Food Wastes	2600	6.0
Fuel oil	20900	48.6
Wyoming Coal	9600	22.3

Table 2.5: Heat content of various waste materials (source: SPM technologies, 1999)

2.4.3.3. Cost to produce

Steam turbine driven Combined Heat and Power (CHP) plants consist of multifaceted interconnected and interdependent systems that need to be individually custom-designed for each capacity and application. The cost breakdown for the associated initial capital costs can be broken down into the following sub-systems:

- 25 % of the cost is taken up by the boiler;
- 20% of the cost to take care of stack gas scrubbing and associated pollution control measures;
- 25% of the cost to cater for fuel preparation and storage;
- 15 % for the steam turbine driven generator; and
- 20% of the cost is taken up by the field construction and the related plant engineering.



Cost & Performance Characteristics	System 1	System 2	System 3
Steam Turbine Parameters			
Nominal Electricity Capacity (kW)	500	3,000	15,000
Turbine Type	Back Pressure	Back Pressure	Back Pressure
Typical Application	Chemicals plant	Paper mill	Paper mill
Equipment Cost ($/kW in 2008)[4]	$657	$278	$252
Equivelant Equipment Cost ($/kW in 2014)[1]	$964	$408	$370
Equivelant Equipment Cost (ZAR/kW in 2014)[2]	R 10,354.11	R 4,381.17	R 3,971.44
Total Installed Cost ($/kW in 2008)	$1,117	$475	$429
Total Installed Cost ($/kW in 2014)[1]	$1,639	$697	$630
Total Installed Cost (ZAR/kW in 2014)[2]	R 17,603.61	R 7,485.89	R 6,760.94
Turbine Isentropic Efficiency (percent)	50%	70%	80%
Generator/Gearbox Efficiency (percent)	94%	94%	97%
Steam Flow (kg/hr)	9,752	57,153	204,117
Inlet Pressure (bar g)	34.5	41.4	48.3
Inlet Temperature (° Celsius)	287.8	301.7	343.3
Outlet Pressure (bar g)	3.4	10.3	10.3
Outlet Temperature (° Celsius)	147.8	185.6	185.6
Combine Heat and Power (CHP) System Parameters			
Boiler Efficiency (percent), HHV	80%	80%	80%
CHP Electric Efficiency (percent), HHV	6.40%	6.90%	9.30%
Fuel Input (MMBtu/hr)	26.7	147.4	549
Fuel Input (GJ/hr)	28.2	155.5	579.2
Steam to Process (MMBtu/hr)	19.6	107.0	386.6
Steam to Process (GJ/hr)	20.7	112.9	407.9
Steam to Process (kW)	5,740.0	31,352.0	113,291.0
Total CHP Efficiency (percent), HHV	79.60%	79.50%	79.70%
Power/Heat Ratio	0.09	0.1	0.13
Net Heat Rate (Btu/kWh)[3]	4,515	4,568	4,388
Net Heat Rate (MJ/kWh)[3]	4.764	4.819	4.630
Effective Electrical Efficiency (percent), HHV	75.60%	75.10%	77.80%
Heat/Fuel Ratio	0.73	0.72	0.7
Electricity/Fuel Ratio	0.06	0.07	0.09

[1] *Inflation rate calculated to correlate with CPI @ 6.6% p.a.*

[2] *Rand/US Dollar exchange rate set @ R10.74 / $1.00 (Aug 2014)*

[3] *The average net heat rate (in Btu/kWh or J/kWh) of an electric-power generating unit is calculated by dividing the total heat input to the system (in units of Btu/h or MJ/h) by the net electric power generated by the plant (in kilowatts), taking into account the boiler, turbine, and generator efficiencies and any auxiliary power requirements.*

[4] *The Equipment cost includes turbine, gearbox, generator, controls and switchgear; boiler and steam system costs are* ***not included***

Table 2.6: Boiler/steam turbine cost performance characteristics (courtesy of EPA, Technology Characterization: Steam Turbines 2008)

The majority of the costs are fixed except for the fuel handling, preparation and storage. These costs will differ from application to application and the types of fuels that will be utilized. The table below gives the cost and efficiency breakdown for typical small-scale steam-driven power generation systems.

The levelized cost of stoker boilers is calculated to be around USD 1880/kW and the maintenance costs on the incinerator and boiler is estimated between 2% to 4% of total investment costs. Maintenance cost is set at R0.07/kW on the turbine system. (IRENA, June 2012)

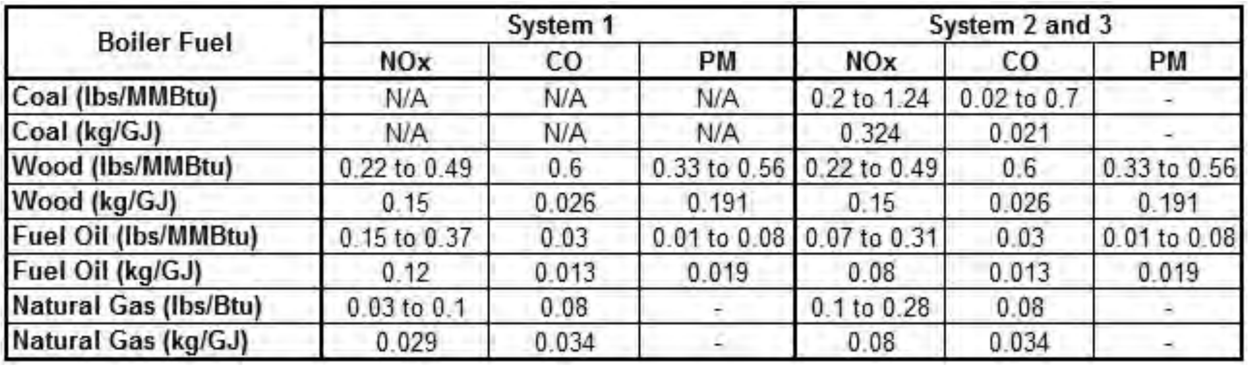
2.4.3.4. Emissions

The fuel utilized to generate the heat inside the incinerators (or boilers systems) isdirectly linked to the types of emissions that will be discharged from the WTE system.

Boilers emissions include:

- Nitrogen oxide (NOx),
- Sulphur oxides (SOx),
- Particulate Matter (PM),
- Carbon monoxide (CO) and
- Carbon dioxide (CO_2).

The table below gives the typical boiler emissions (quantities) for the small generation systems that were discussed in the previous section, as per different fuel types.



Boiler Fuel	System 1			System 2 and 3		
	NOx	CO	PM	NOx	CO	PM
Coal (lbs/MMBtu)	N/A	N/A	N/A	0.2 to 1.24	0.02 to 0.7	-
Coal (kg/GJ)	N/A	N/A	N/A	0.324	0.021	-
Wood (lbs/MMBtu)	0.22 to 0.49	0.6	0.33 to 0.56	0.22 to 0.49	0.6	0.33 to 0.56
Wood (kg/GJ)	0.15	0.026	0.191	0.15	0.026	0.191
Fuel Oil (lbs/MMBtu)	0.15 to 0.37	0.03	0.01 to 0.08	0.07 to 0.31	0.03	0.01 to 0.08
Fuel Oil (kg/GJ)	0.12	0.013	0.019	0.08	0.013	0.019
Natural Gas (lbs/Btu)	0.03 to 0.1	0.08	-	0.1 to 0.28	0.08	-
Natural Gas (kg/GJ)	0.029	0.034	-	0.08	0.034	-

Table 2.7: Typical boiler emissions ranges (courtesy of EPA, Technology Characterization: Steam Turbines 2008)

Other waste produced from the incineration process includes ash and slag, which makes up approximately 20% to 25% of waste combusted.

2.4.4. Reciprocating engine-driven generator - means of operation

Reciprocating engine driven generators consist of the following basic components:

- Induction generator;
- Reciprocating engine (the drive force);
- Fuel supply system; and
- Exhaust system (can also contain co-generation capabilities).

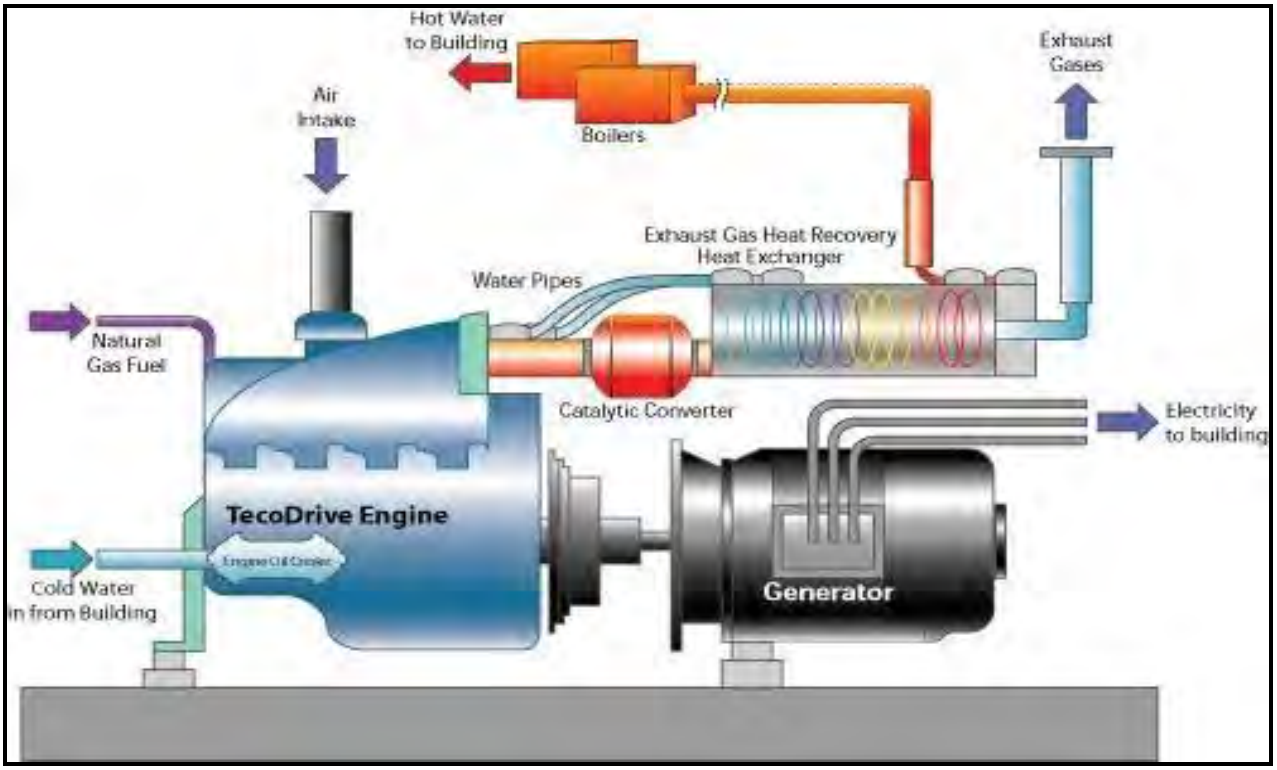


Figure 2.13: Gas fired reciprocating co-generation system (courtesy of EYP energy, 2012)

Figure 2.13 above provides a graphical illustration of the power generation system with all its components.

2.4.4.1. The reciprocating engine

Reciprocation engines can be divided into two main types of ignition configurations, namely:

- Electrical spark ignition engines; and
- Compression ignition.

Electrical spark ignited engines can be fuelled by either natural gas, methane (can be extracted from a landfill), propane, normal gasoline or even a combination of gases. Compression ignited engines are designed to be in essence fuelled with diesel but, heavy oil can be utilized as an alternative fuel source for combustion. Compression ignited engines can the also be set up to be run with a combination of fuels of which natural gas will be the primary fuel source with diesel used only as a pilot fuel.

Advantages for using natural gas fueled reciprocating engines include:

- Fast start-up when needed;
- Lower initial cost;
- Very good reliability;
- Distinct load-following characteristics; and
- Substantial heat recovery potential.

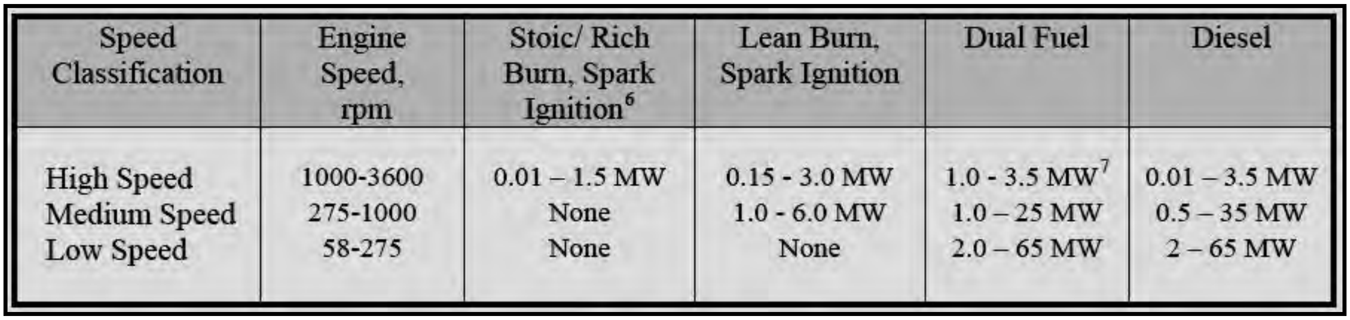
Reciprocating engines are more expensive to maintain than gas turbine engines but it is possible to have the maintenance done in-house or by local professionals which will save on the maintenance cost. This can save time on the downtime of the system compared to other drive trains like turbine engines (Energy and Environment Analysis Incorporated, 2008).

Reciprocating engines are designed to deliver a wide range of torque to drive different-size generators. The higher the torque ratings of these engines the lower the speed will be at which these engines run. The motors are thus classified into three different speed ranges:

- High speed;

- Medium speed; and
- Low speed.

The table below gives the different engine types and the typical speed to power ratios according to the fuel types used.



Speed Classification	Engine Speed, rpm	Stoic/ Rich Burn, Spark Ignition[6]	Lean Burn, Spark Ignition	Dual Fuel	Diesel
High Speed	1000-3600	0.01 – 1.5 MW	0.15 - 3.0 MW	1.0 - 3.5 MW[7]	0.01 – 3.5 MW
Medium Speed	275-1000	None	1.0 - 6.0 MW	1.0 – 25 MW	0.5 – 35 MW
Low Speed	58-275	None	None	2.0 – 65 MW	2 – 65 MW

Table 2.8: Reciprocating engine types by speed. (courtesy of SFA Pacific Inc.)

The engine will be designed to run in tandem with the requirements of the generator to which it is connected, to ensure that the speeds at which the generation system are designed for are met. This encompasses that the motor will be running at a fixed speed setting in order to ensure that the power generation system delivers a constant 50 or 60 Hz output (Energy and Environment Analysis Incorporated, 2008).

2.4.4.2. Efficiencies of reciprocation-driven generation systems

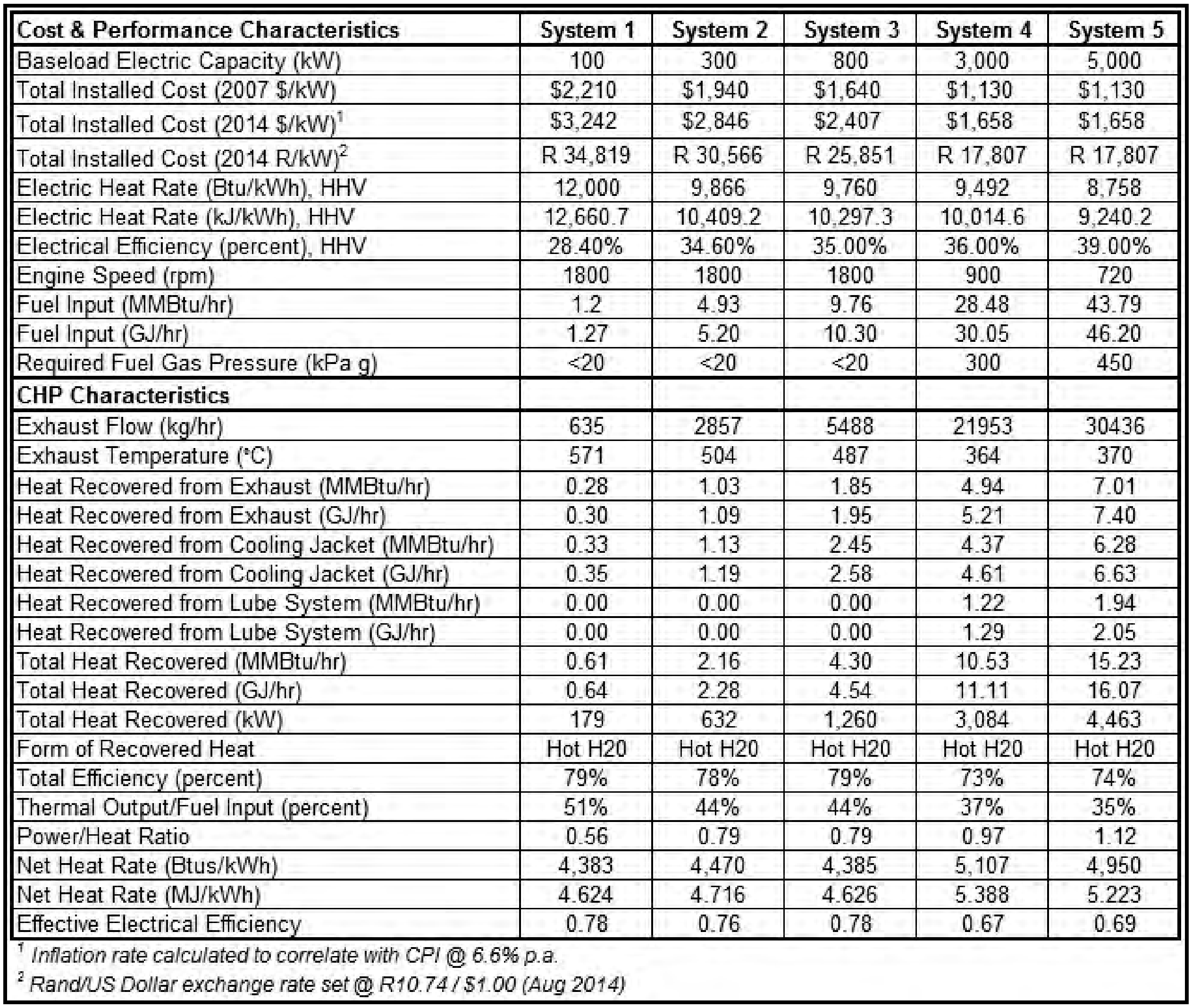
Electrical efficiencies of natural gas-fuelled engines will be in the range from 30% Low Heat Value (LHV) for small engines (less than 100kW) to over 40% LHV for larger lean burn engines (typically bigger than 3MW).

When the system is utilized as a co-generation system that will incorporate steam generation, the total efficiency of this type of generation is greatly enhanced. Waste heat energy recovered from the exhaust system and engine cooling system to be further utilized to produce low pressure steam and also hot water for Combined Heat and Power (CHP) applications.

Table 2.9 below gives an indication on various sizes of reciprocation-driven generation systems. The table contains various calculations relating to the emissions and also the total installed cost for the generation system. The five systems that were included in this table are:

- System 1 – Ipower Model ENI 85 which delivers 85kW
- System 2 - GE Jenbacher JMS 312 GS-N.L which delivers 625 kW
- System 3 - GE Jenbacher JMS 320 GS-N.L which delivers 1050 kW
- System 4 - Caterpiller G3616 LE which delivers 3 MW
- System 5 - Wartsila5238 LN which delivers 5 MW

The data in table 2.9 also reinforce the fact that electrical efficiencies will increase as engine size becomes larger. This is also related to the absolute quantity of thermal energy that decreases in accordance with the electrical efficiency, which in turn will lead to a decrease of useful thermal energy. The calculations and detail data which form the basis for the data captured in this table can be obtained from Annexure A - review of the emissions standards in RCSA SECTION 22a-174-42 (Available from: http://ct.gov/deep/lib/air/regulations/proposed_and_reports/air_emmisions_from_smaller-scale_electric_generation_resources_review.xlsx)



Cost & Performance Characteristics	System 1	System 2	System 3	System 4	System 5
Baseload Electric Capacity (kW)	100	300	800	3,000	5,000
Total Installed Cost (2007 $/kW)	$2,210	$1,940	$1,640	$1,130	$1,130
Total Installed Cost (2014 $/kW)[1]	$3,242	$2,846	$2,407	$1,658	$1,658
Total Installed Cost (2014 R/kW)[2]	R 34,819	R 30,566	R 25,851	R 17,807	R 17,807
Electric Heat Rate (Btu/kWh), HHV	12,000	9,866	9,760	9,492	8,758
Electric Heat Rate (kJ/kWh), HHV	12,660.7	10,409.2	10,297.3	10,014.6	9,240.2
Electrical Efficiency (percent), HHV	28.40%	34.60%	35.00%	36.00%	39.00%
Engine Speed (rpm)	1800	1800	1800	900	720
Fuel Input (MMBtu/hr)	1.2	4.93	9.76	28.48	43.79
Fuel Input (GJ/hr)	1.27	5.20	10.30	30.05	46.20
Required Fuel Gas Pressure (kPa g)	<20	<20	<20	300	450
CHP Characteristics					
Exhaust Flow (kg/hr)	635	2857	5488	21953	30436
Exhaust Temperature (°C)	571	504	487	364	370
Heat Recovered from Exhaust (MMBtu/hr)	0.28	1.03	1.85	4.94	7.01
Heat Recovered from Exhaust (GJ/hr)	0.30	1.09	1.95	5.21	7.40
Heat Recovered from Cooling Jacket (MMBtu/hr)	0.33	1.13	2.45	4.37	6.28
Heat Recovered from Cooling Jacket (GJ/hr)	0.35	1.19	2.58	4.61	6.63
Heat Recovered from Lube System (MMBtu/hr)	0.00	0.00	0.00	1.22	1.94
Heat Recovered from Lube System (GJ/hr)	0.00	0.00	0.00	1.29	2.05
Total Heat Recovered (MMBtu/hr)	0.61	2.16	4.30	10.53	15.23
Total Heat Recovered (GJ/hr)	0.64	2.28	4.54	11.11	16.07
Total Heat Recovered (kW)	179	632	1,260	3,084	4,463
Form of Recovered Heat	Hot H20	Hot H20	Hot H20	Hot H20	Hot H20
Total Efficiency (percent)	79%	78%	79%	73%	74%
Thermal Output/Fuel Input (percent)	51%	44%	44%	37%	35%
Power/Heat Ratio	0.56	0.79	0.79	0.97	1.12
Net Heat Rate (Btus/kWh)	4,383	4,470	4,385	5,107	4,950
Net Heat Rate (MJ/kWh)	4.624	4.716	4.626	5.388	5.223
Effective Electrical Efficiency	0.78	0.76	0.78	0.67	0.69

[1] *Inflation rate calculated to correlate with CPI @ 6.6% p.a.*

[2] *Rand/US Dollar exchange rate set @ R10.74 / $1.00 (Aug 2014)*

Table 2.9: Gas engine CPH typical performance parameters (source: EEA ICF, 2007)

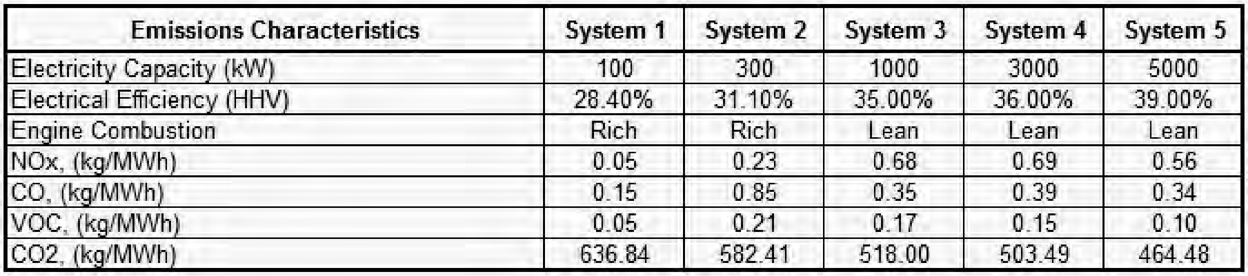
2.4.4.3. Emissions per kW

Emissions from the exhaust systems of the reciprocating engine are the major source of air pollution that is linked to this type of power generation. Emission gases include:

- Nitrogen Oxides (NO_x);
- Carbon Monoxide (CO);
- Volatile Organic Compounds (VOC’s);
- Unburned non-Methane Hydrocarbons; and
- Carbon Dioxide (CO_2).

In the event that the engine is fuelled by waste gas, it must be taken into account that the existing emission gases would have been present when hydrocarbons are burned through flare systems.

The table below gives an indication of the amount of emissions that can be expected from the five generation systems discussed in the above paragraphs.



Emissions Characteristics	System 1	System 2	System 3	System 4	System 5
Electricity Capacity (kW)	100	300	1000	3000	5000
Electrical Efficiency (HHV)	28.40%	31.10%	35.00%	36.00%	39.00%
Engine Combustion	Rich	Rich	Lean	Lean	Lean
NOx, (kg/MWh)	0.05	0.23	0.68	0.69	0.56
CO, (kg/MWh)	0.15	0.85	0.35	0.39	0.34
VOC, (kg/MWh)	0.05	0.21	0.17	0.15	0.10
CO2, (kg/MWh)	636.84	582.41	518.00	503.49	464.48

Table 2.10: Emission data characteristics of gas engines (source: EEA, ICF, 2007)

2.4.4.4. Resource requirements

Natural gas-driven engines are designed to run on a variety of fuel options, which makes them ideal to be used in utilizing waste gasses that are normally flared. The engines can be run in a combination of fuels and this flexibility allows the engines to be run at the desire of the end user.

2.4.4.5. Min fuel requirements

Natural gas driven engines (spark ignition) are designed to run on a variety of fuel options, which are:

- Liquefied Petroleum Gas (LPG), which contains mixes of propane and butane;
- Bio-fuel gas, any of the combustible gasses produced from the organic degradation process which includes mainly methane;
- Sour gas or unprocessed natural gas extracted directly from gas wells; and
- Industrial waste gases, which are deemed to be flared.

Compression engines such as diesel-fuelled engines can be driven with a variety of fuel combinations. Start-up sequences can typically be done with diesel fuel and then the fuel can be switched over to another mixture of hydrocarbon-based fuel.

Flare gas that contains hydrocarbons can be used as a fuel source to power these types of generation units. The hydrocarbon-rich gas streams that are deemed to be flared in stack systems can be routed through retrofitted gas recovery units that compress and store these gases.

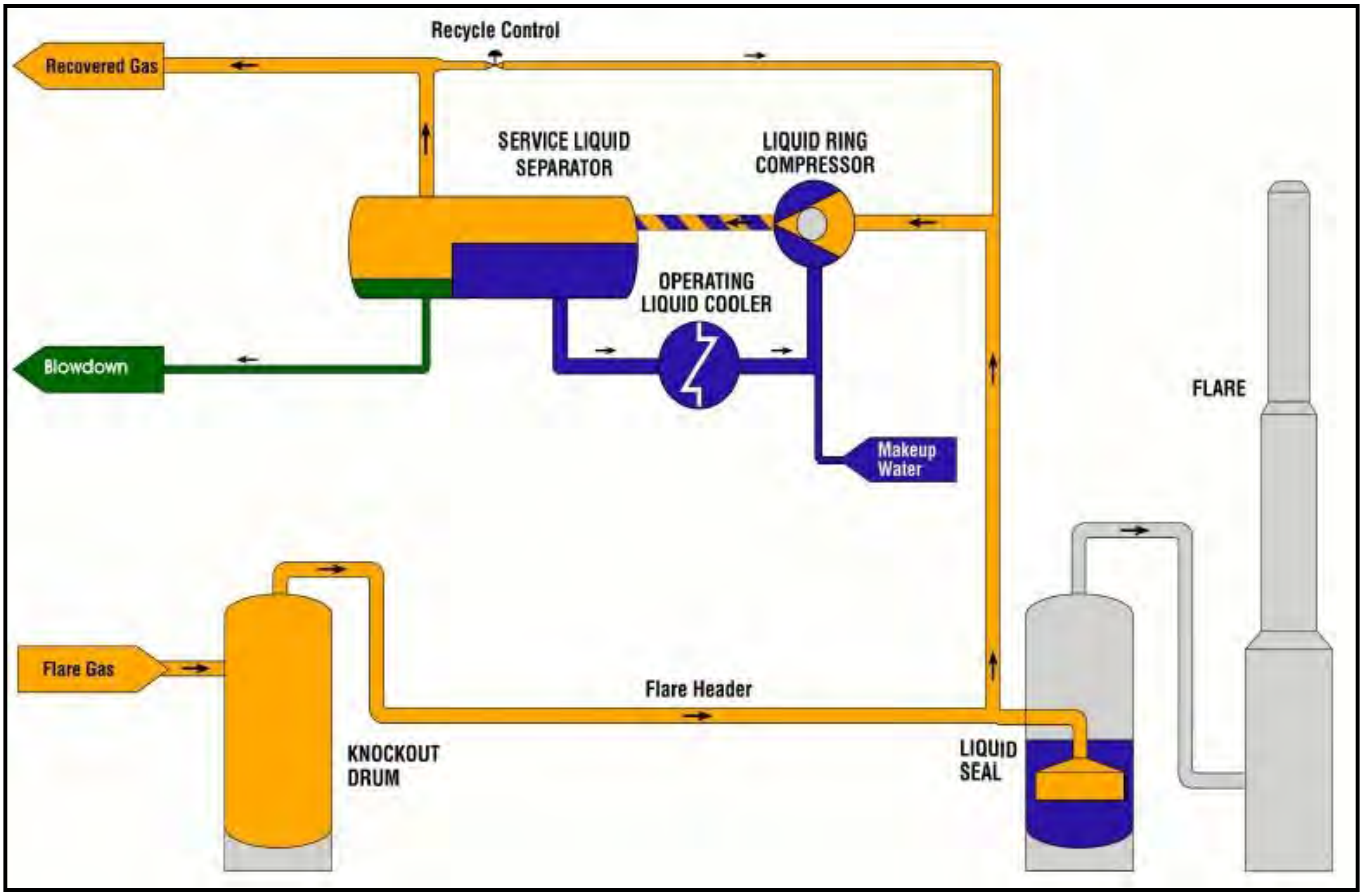


Figure 2.14: Flare gas recovery system (courtesy of John Zink, 2010)

Flare gas recovery systems are installed on several polymerization plants across the United States of America. The principle of operation is based on intercepting the flare gas from the flare header and then recycling the gas through the use of a liquid ring compressor. The outlet of this compressor is fed through a liquid separator to remove most of the condensed impurities.

Recovered gas is then fed back to a storage facility for use to fuel power generation units.

Advantages of flare gas recovery:

- Improved public relations – due to reduced visual air pollution;
- Reduced plant flare fuel gas consumption;
- Reduced green house gas emissions from the production facility;
- Reduced flaring noise, light, and odor;
- Reduced steam consumption for the flare; and
- Extended flare tip life – through reduced flaring (Blanton, 2010).

The installed cost for flare gas recovery systems is between $600k to $950k for units which include the compression systems but, exclude storage vessels (Environ, 2008).

Poly ethylene wax is also a hydrocarbon fuel that has a significant heat factor (18600 BTU/lbs) and can be processed to form a liquid fuel (base oil and naphtha gas). This can be achieved by:

- Catalytic de-waxing – a high temperature and pressure process that utilizes a catalyst to crack the wax molecules into shorter strings to form gas or naphtha; and
- Wax hydro-isomerization – a similar process to convert or isomerize the wax into high quality base oil.

The above mentioned processes were studied and it was found that both processes were very expensive and consume a lot of heat energy which will not be applicable for the purposes of this study (Sequeira et al., 1994).

2.4.4.6. Cost to produce

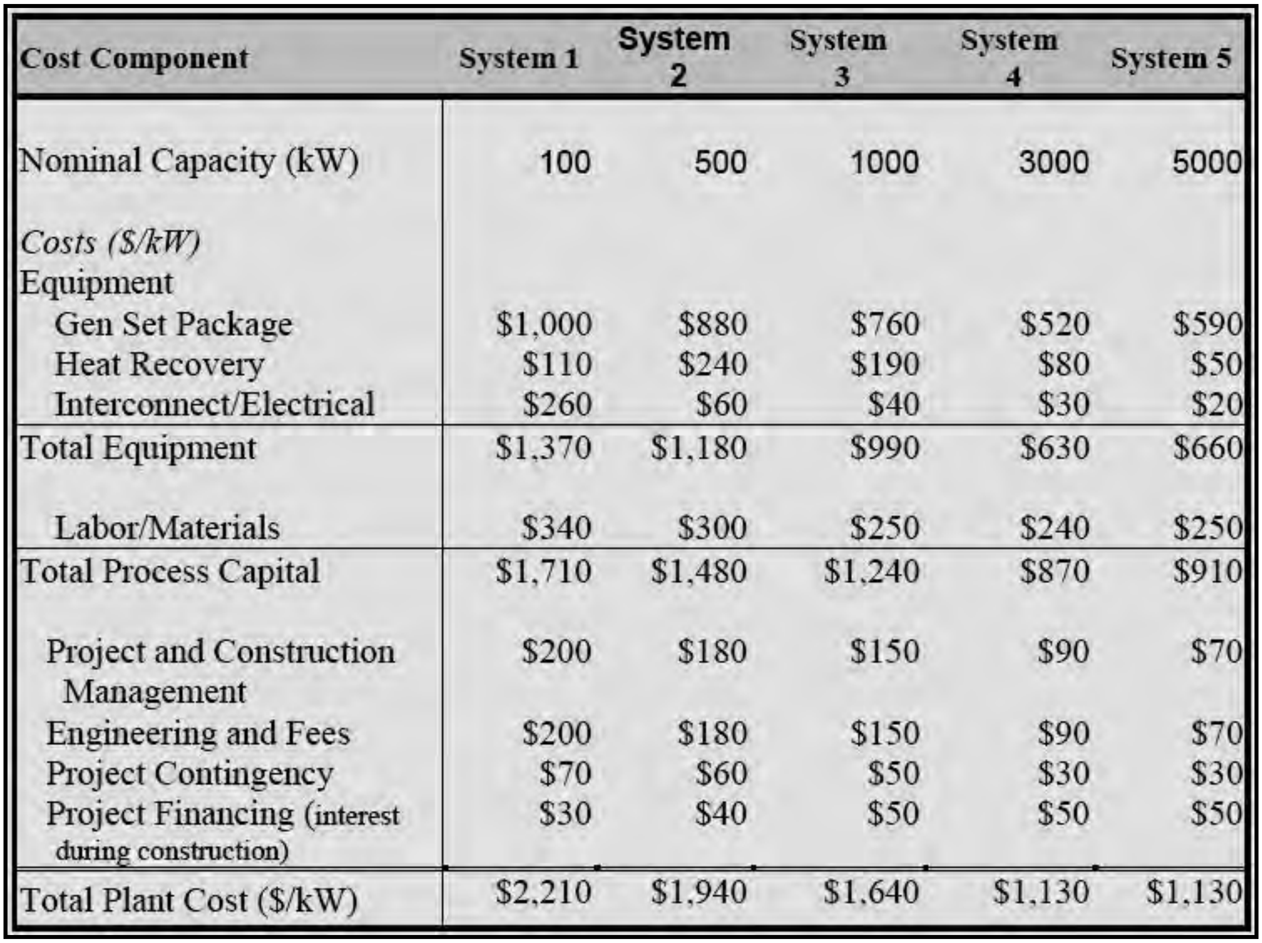
The costs to produce electricity by utilizing waste gases as fuel source will be greatly influenced by the amount of fuel gas ratios that the engine is feeding on. This variable makes it almost impossible to calculate what the fuel to run cost will be. The overall cost per kW will still be a valuable indicator which will indicate what machine and size of generation system will be of most value.

It is therefore imperative that the consumption specifications of each manufacturer need to be carefully studied to ensure that the most efficient machine is chosen for each unique application. Typical maintenance cost for a Jenbacher generator is calculated to be at $4.04 (2013) per operating hour.

Included for the purposes of this study is a cost breakdown as per the five power systems discussed in the sections above. It is clear from the costing table below that the economy of scale has the biggest influence on the cost per installation. Project and construction costs, per kW, will be drastically reduced when bigger generation units are installed.

Smaller generation systems may be more costly per kW but it should be taken into account that the total capital outlay will be significantly smaller than that of the bigger generation units. Typically as per table 2.11, the total capital cost will add up to $221k (2007) for a 100kW unit and a massive $5 650k (2007) for the 5 MW power-generation units.

Reciprocating generation units allow for the generation of hot water (smaller units) and also low-pressure steam for the bigger applications. The cost savings associated with the generation of these utilities will vary along with the size of the unit installed (Energy and Environment Analysis Incorporated, 2008).



Cost Component	System 1	System 2	System 3	System 4	System 5
Nominal Capacity (kW)	100	500	1000	3000	5000
Costs ($/kW)					
Equipment					
Gen Set Package	$1,000	$880	$760	$520	$590
Heat Recovery	$110	$240	$190	$80	$50
Interconnect/Electrical	$260	$60	$40	$30	$20
Total Equipment	$1,370	$1,180	$990	$630	$660
Labor/Materials	$340	$300	$250	$240	$250
Total Process Capital	$1,710	$1,480	$1,240	$870	$910
Project and Construction Management	$200	$180	$150	$90	$70
Engineering and Fees	$200	$180	$150	$90	$70
Project Contingency	$70	$60	$50	$30	$30
Project Financing (interest during construction)	$30	$40	$50	$50	$50
Total Plant Cost ($/kW)	$2,210	$1,940	$1,640	$1,130	$1,130

Table 2.11: Estimated installation cost breakdown for typical gas engine generators (courtesy of EEA ICF, 2007)

2.5. Kinetic energy harnessed power turbine generators

2.5.1. Introduction

This section will present information on electricity generation by harnessing kinetic energy from water and wind. These elements are available in abundance in the natural environment depending on your geographical area.

Both water and wind can be used to drive induction-power generators, which were discussed in detail in the previous section of this chapter. The following sections will concentrate on researching the different technologies that are available to harness the kinetic properties of these two elements. Research will be aimed at presenting the options available in order to drive induction-power generators for use in the industrial sector in the most cost-efficient way.

Due to the geographical location of the Safripol production facility, the study will not research large-scale hydro- and wind-generation technologies, but merely focus on technologies that recover process-based energy.

2.5.2. Water-driven generators

2.5.2.1. Introduction

Water is one of the predominantly used utilities in the industrial sector. It is used to convey mediums, for cooling processes, heating processes; fabrication processes and sanitation needs as well as being a major ingredient in products.

Once in movement it possesses great kinetic energy due to the density of the medium, and this attribute has been exploited over many centuries in order to power water mills and transport heavy timbers. Today we utilize this energy primarily to drive induction generators to generate electricity (Hydro-power).

2.5.2.1.Types of generation configurations

Hydro power generating plants can be a variety of sizes and the types of arrangements that will act as the input to the generation system are differentiated. Generation plants types that are grouped according to their generation capacity are:

- Large hydro plants – 100 MW or more
- Medium hydro plants – 20 MW to 100 MW
- Small hydro plants – 1 MW to 20 MW
- Mini-hydro – 100 kW to 1 MW
- Micro-hydro – 5 kW to 100 kW
- Pico-hydro – less than 5 W

Large scale hydro-electric power can be generated by harnessing potential energy of stored water (in reservoirs) then allowing the water to flow across the generator which converts this kinetic energy into electrical energy.

This magnitude of this kinetic energy depends on the height difference between the reservoir and the outflow across the turbine generator. This difference in height is called the head as seen in figure 2.15 (Irena, 2012).

The larger the head of the installation is the more kinetic energy will be generated in order to drive the turbine.

Power (kW) $=10 \times \text{Head (m)} \times \text{Flow (m}^3\text{/s)} \times \eta$

η = turbine-generator efficiency ~80% (NREL, 2012)

Kinetic energy is thus dependent on the velocity of the water flow at the turbine. This energy is called hydro-kinetic energy (UCASA, 2008).

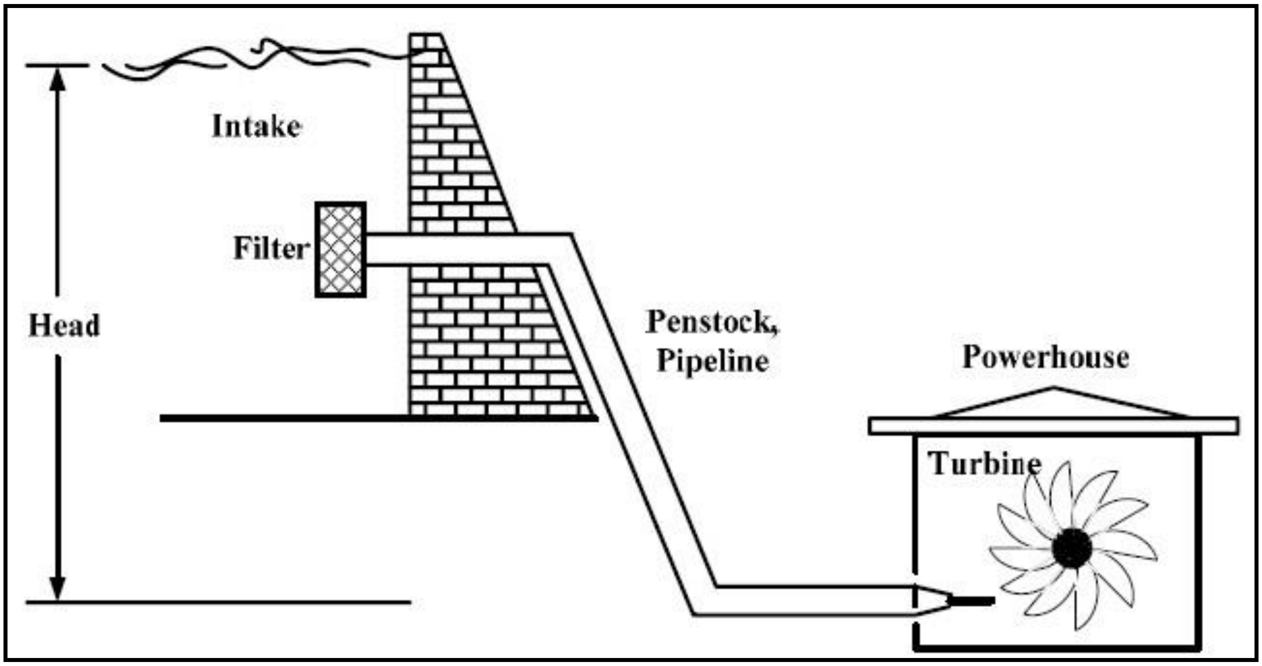


Figure 2.15: Hydro-electric head (source: ARET, 2008)

Classification by hydro-electrical facility types are:

- Run of river type
- Storage or reservoir type
- Pumped storage type
- In-stream technology (IPCC SRREN, 2011)

Kinetic energy can be achieved in the industrial sector by means of harnessing water that is in motion due to pumped systems. This can be in the form of return water cooling units or even the supply from municipal feeds to production facilities (Parrish, 2012).

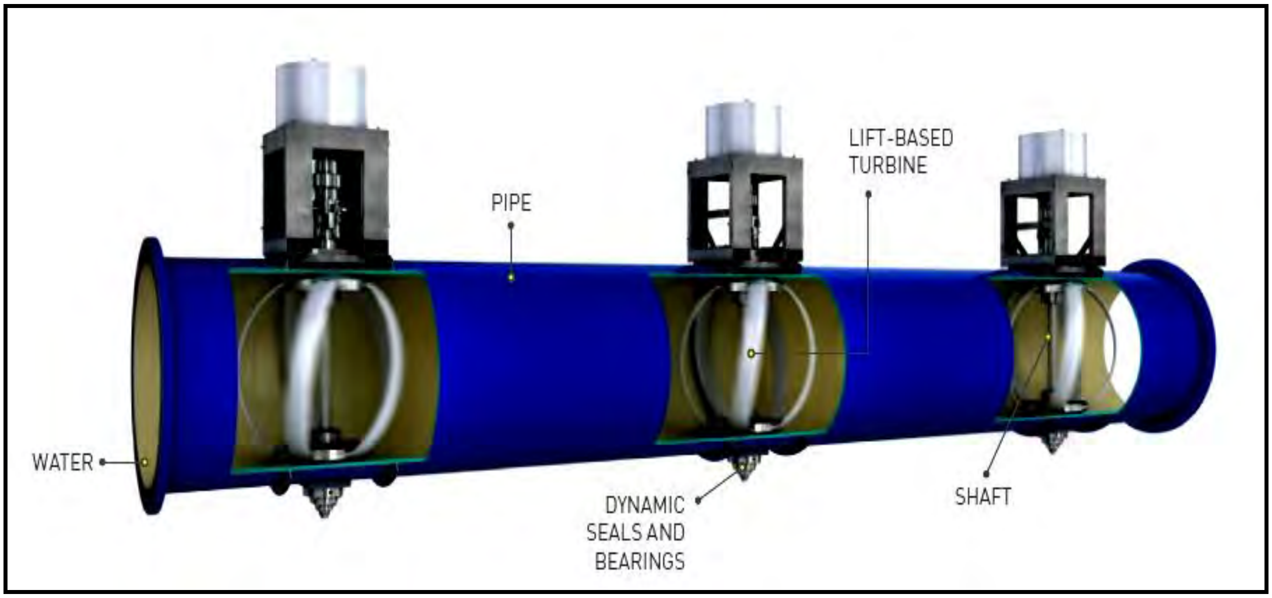


Figure 2.16: Harnessing energy from gravity-fed water pipes (courtesy of Lucid Energy, 2012)

Turbine generators are fitted with different wheel technologies which include:

- Pelton wheel;
- Cross-flow – horizontal axis;
- Francis turbine; and
- Cross-flow – vertical axis.

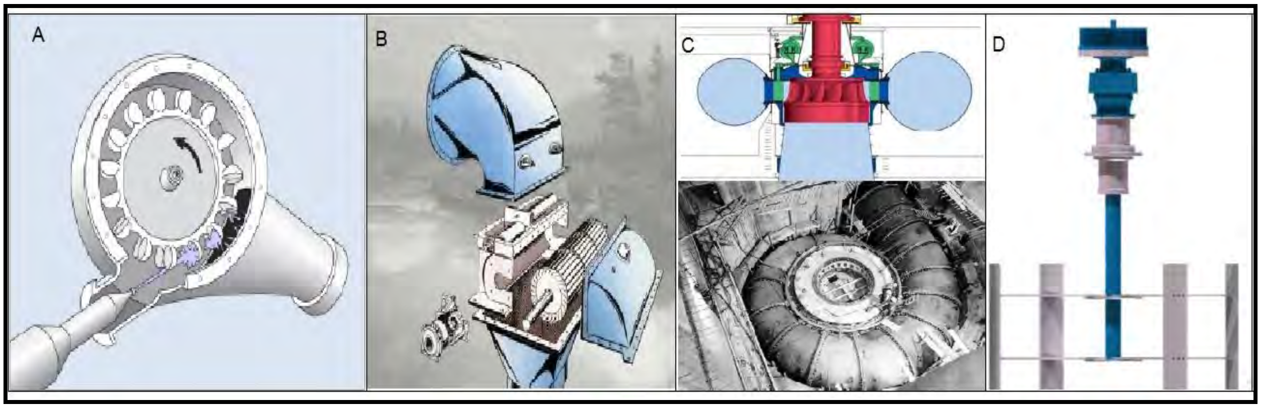


Figure 2.17: A: Pelton wheel, B: Cross-flow turbine (horizontal axis), C: Francis turbine, D: Cross-flow turbine (vertical axis) (courtesy: NREL, 2012)

Hydro turbines can be divided into two categories:

- Impulse turbines
- Reaction turbines

Reaction turbines differ from impulse turbines in the way that the rotational energy is produced from the inflow of water onto or over the turbine. In the reaction turbine (e.g. the Francis turbine, Fig 2.17) the water flows over the blades in a spiral pattern created by the vortex effect due to the turbine design. These turbines utilize the combination of radial and axial forces exerted by the water flow and therefore will require an encapsulating casing. Reaction turbines are best applied for use in systems with a lower water head and higher flow properties.

Impulse turbines (e.g. Pelton wheel, Fig 2.17) utilize the force of accelerated water impacting on the turbines curved bucket like blades. This will cause a flow-directional change which in turn will produce the momentum needed to turn the turbine. These types of turbines do not always require to be encased but in order to minimize water splashing they are most of the times covered. Impulse turbines are designed for applications with high head and low flow characteristics (Johnson & Hart, 2011).

2.5.2.2. Conduit hydro-power – in-stream technology

This type of hydro power takes advantage of existing piped systems or canals that are already in use for other purposes. Most infrastructures in the industrial sector make use of pipe networks to convey water which is used as a utility in the production processes.

This makes for ideal installation opportunities for in-pipe hydro-electric systems, due to the existence of pressurized water that is already in motion. Conventional hydroelectric plants have the extra financial burden to construct very expensive storage and run-off systems to ensure that there is enough head pressure to provide sufficient flow rates.

Many of the water supply systems in industry makes use of downhill-sloped pipe networks that ensures that the water is supplied by municipalities to the end users at sufficient system pressures. Effluent run-off from production facilities are also build at a downhill decline and this provides the opportunity to install canal generation systems (Lucid Energy, 2012).

2.5.2.3. Efficiencies

The following aspects need to be taken into account when determining the full potential of a hydro-electric plant:

- The availability of water as driving force.
- The amount of water loss due to spillages and leakages.
- The difference in head pressure between the intake and the downstream outlet of the system.
- Hydraulic losses due to friction and pipe alteration (bends and elbows) which will cause permanent velocity losses.
- The conversion efficiency of electro-mechanical equipment (induction generators).

All the above-mentioned points will contribute when determining the total efficiency of the hydro-power generation system. Most of the variables are not constant and may vary over a period of time, which in turn will cause deviations of the total system efficiency. It is also important to note that during the power-generation process there are no fugitive emissions, which makes this one of the most environmentally friendly types of power generation.

The total energy transformation from kinetic energy to rotational mechanical energy in the modern hydro-electric generation plants is well over 90%, and the modern generators run at 99% efficiency (IPCC SRREN, 2011).

2.5.2.4.Resources needed

The main resources for hydro-electric power generation are:

- Water in motion;
- Capital Intensive (this type of power generation is expensive to install); and
- Infrastructure (pipes and canals).

In essence you will not be able to drive a hydro-turbine without water. Therefore you will need water which is in motion, with the minimum amount of kinetic energy required to drive the type of turbine according to their specifications.

To channel water to the turbines is very expensive due to the fact that you will need to incorporate civil and piping construction as part of the installation costs of the power generation plant. Vast savings on the total project cost can be made by using In-stream technologies that can be installed into existing pipe networks (Lucid Energy, 2012).

2.5.2.5.Cost to produce

It is important to understand that hydro-electricity generation will differ from each of the four facility types and that the capital requirements to install such facilities are very much site-specific. For this reason the costing should also be broken into groups that will represent the types of installation.

	Installed costs (USD/kW)	Operations and maintenance costs (%/year of installed costs)	Capacity factor (%)	Levelised cost of electricity (2010 USD/kWh)
Large hydro	1 050 - 7 650	2 - 2.5	25 to 90	0.02 - 0.19
Small hydro	1 300 - 8 000	1 - 4	20 to 95	0.02 - 0.27
Refurbishment/upgrade	500 - 1 000	1 - 6		0.01 - 0.05

Table 2.12: Installed cost per kW (courtesy of Irena, 2012)

Levelized Cost of Energy (LCOE) is a metric used by the U.S. Department of Energy (DOE) and others to evaluate the relative costs of electric-generating projects and the impact of technology design changes.

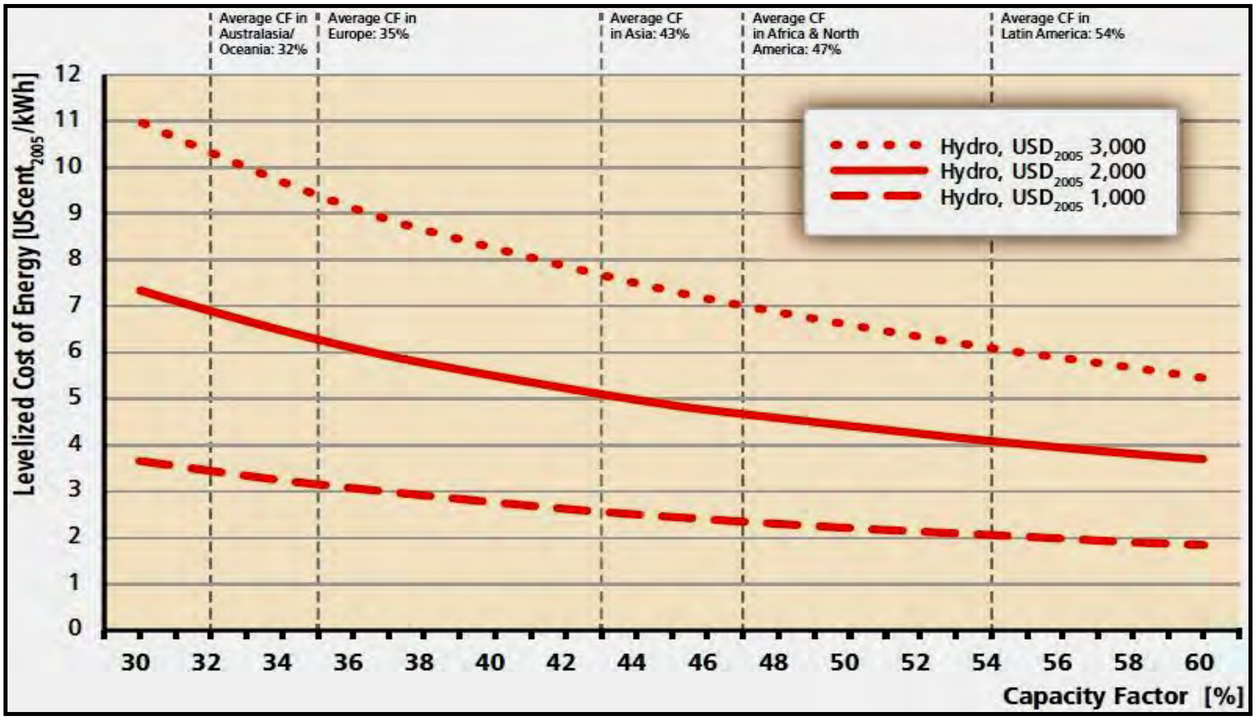


Figure 2.18: LCOE of hydropower graph (courtesy of IPCC SRREN, 2011)

In simple terms, LCOE is defined as:

LCOE=present value of total costs / lifetime energy production (megawatt-hours) (NREL, 2011)

Investment costs of hydro-electrical generation plants for smaller plants can typically be between USD 400 to USD 500 per kW generated but realistic projects on large scales falls between USD 1000 to USD 3000 per kW generated. The graph above (Figure 2.18) provides the cost of electricity according to these three project classes (IPCC SRREN, 2011).

The cost to produce hydro-power from using in-conduit technology is not that well documented, since this is a new form of application in the past few years. A local distributor of renewable energy hardware (*Alternagy*) does provide the hardware costing.

Figure 2.19: Low head turbine model LH-3 (courtesy of Alternagy, 2014)

The data provided by *Alternagy* are tabled in Table 2.11 and do provide an understanding with regard to the hardware costs which average at R26, 117 per kilo Watt.

Alternagy						
Model	**Head (m)**	**Rate of Flow (l/s)**	**Power (kW)**	**Weight (kg)**	**Price (ZAR)**	**Unit Cost per kW**
CJD 20	30 -45	60-100	20	490	R 452,100.00	R 22,605.00
CJ 10	30 - 38	40-50	10	300	R 227,450.00	R 22,745.00
CJ12	28-35	50-60	12	325	R 308,230.00	R 25,685.83
CJD 15	30-40	60-70	15	350	R 339,060.00	R 22,604.00
CJD 30	38-45	90-120	30	530	R 678,170.00	R 22,605.67
MH 10	11	165	10	91.3	R 262,000.00	R 26,200.00
MH 6	7	156	6	34.3	R 200,360.00	R 33,393.33
LH 0.3	1.8	40	0.3	29	R12,520.00	R41,733.33
LH 1	2.5	50	1	43	R 25,770.00	R 25,770.00
LH 3	11	45	3	140	R 100,350.00	R 33,450.00

Table 2.13: Hardware cost of in-conduit turbine generators (data sourced from: Alternagy, 2014)

2.5.3. Wind driven generators

2.5.3.1. Introduction

Wind can be described as a gas mixture (air and nitrogen) which is in motion. As in the case of water utilization, we have been using this driving force to power wind-mills to perform various functions. In the modern industrial sector we utilize many forms of moving gasses for all kinds of purposes. Dry gases can be utilized to perform the following functions:

- drying functions;
- conveying medium;
- driving pneumatic systems, etc.

The development of this type technology has been fast-tracked by a global drive to invest in renewable energy. Wind turbines are used to drive induction generators of various sizes to supply electricity that can be tied into the utility grid or to supply electricity to the grid users.

2.5.3.2. Types of generation configurations

Wind-turbine blade configurations can be designed to suit the specific requirements of the application that the turbine is to be installed in. Turbine-blade configurations include, but are not limited to, the following configurations:

- Single bladed, double bladed or multi-bladed
- Upwind configuration
- Downwind configuration
- Multi rotor
- Enfield Andreau
- Counter-rotating blades
- Crosswind savonius
- Crosswind paddles

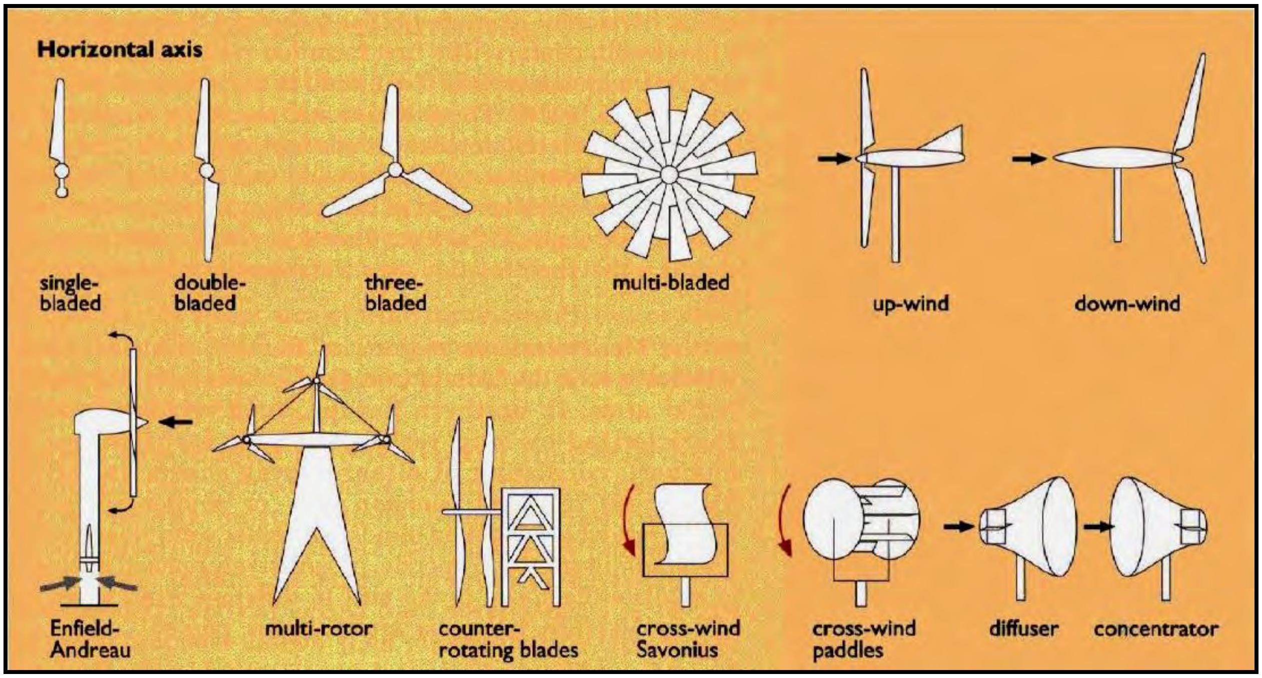


Figure 2.20: Turbine blade configurations (courtesy of Eldridge, 1975)

Diffusers and concentrators are used to obtain higher efficiencies from the installations and other configurations can be utilized to ensure ease of future maintenance. Factors that will also impact the configuration are cost, directionality and speed of rotation (Kammen, Nov 2013).

The different rotor and blade configurations can be used to satisfy the requirements of different applications which include:

- Masted systems
- Ducted exhaust gas
- Micro-turbines
- Solar updraft towers
- Low-noise applications

Solar updraft towers are a new development and this technology will combine wind power with solar power in order to create the driving force for the turbines (Bergermann & Weinrebe et al., 2010).

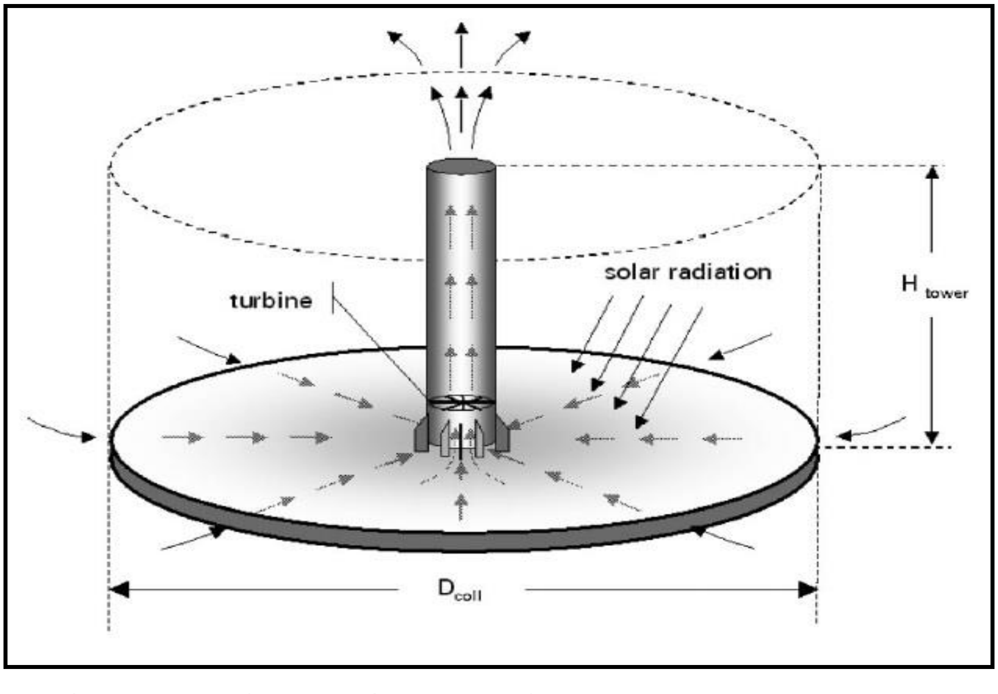


Figure 2.21: Solar updraft tower (courtesy of Bergermann & Weinrebe, 2010)

Figure 2.22 illustrates the basic components of the wind-turbine power-generation system which are:

- Blade – used to drive the rotor;
- Tower – used to support the turbine high up in the air;
- Rotor – connected to the gearbox, acts as a transmission shaft;
- Gearbox – used to increase the rotations on the generator
- Generator – used to produce power;
- Yaw drive and motor – used to point the turbine into the wind as direction changes; and
- Brake – to stop the system and prevent over speeding.

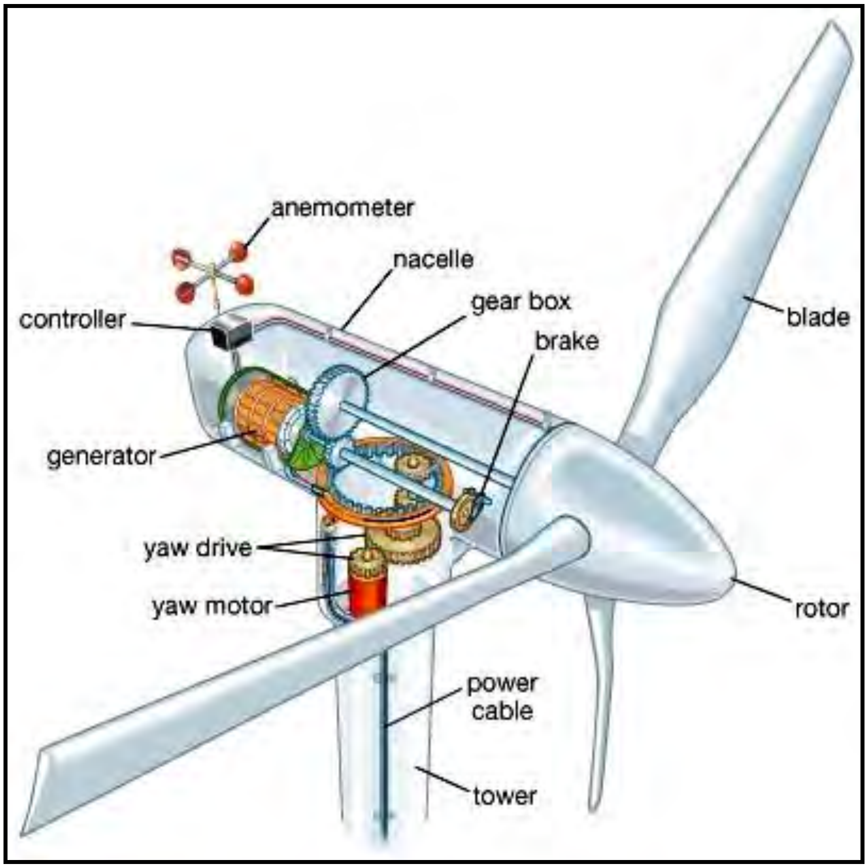


Figure 2.22: Basic components of a wind turbine (courtesy of Encyclopaedia Britannica, 2009)

Larger-scale turbines are fitted with blades that can adjust the blade pitch automatically in order to control the speed at which the turbine rotates. This is an important design feature to allow the turbine to operate at a constant speed during alternating wind speeds. This feature is very important when selecting the type of generation unit that will be fitted to the turbine (Muljadi & Butterfield et al., 1999).

2.5.3.3. Types of generators used with wind turbines

There are three major groups of generators used in conjunction with wind turbines, which are:

- Induction generator;
- Permanent magnet alternators; and
- Brushed DC motors.

Induction generators are in essence a type of induction motor of which the basic principles are set out earlier in this chapter. Used in combination with the wind turbine there are how ever a few points to take note of:

- Induction generators, generate power when they are rotated faster than the synchronous frequency of the correspondent motor.
- They are electrically and mechanically simpler than other types of power generators.
- They are self-exciting, meaning there are no permanent magnets to supply the flux to the generation field. Like an induction motor the initial flux will be supplied either from an external power supply or capacitor.
- They do not have brushes or a commutator.
- If the induction generator is rotated faster than the rate of the rotating flux, it will generate power at the synchronous frequency (50 Hz).
- Induction generators require running at typically 1500 rpm or more, which necessitates the use of gearboxes (Meyers et al., 2014).

Permanent Magnet Alternators (PMA) are typically fitted with permanent magnets mounted on the rotor as well as a set of electromagnets that are usually mounted on the stator. The electromagnets are wired in a configuration to generate power in either a three phase wye or a delta manner. PMA are very efficient with a typical range from

60% to 95%, averaging at about 70%. Permanent magnet alternators can be easily rectified to charge a DC battery bank or they can be tied to the utility grid via the use of a grid connector (Meyers et al., 2014).

Brushed DC motors are generally used to power residential homes but the efficiency is not as good as other generator technologies. High-quality units will run, at best, at an efficiency of 70%. This type of generator will operate at low rotational speeds and are readily available (Meyers et al., 2014).

2.5.3.4. Efficiencies

The total system efficiency of a wind turbine power generation system will run between 20% and 40%. This value represents the total conversion of the kinetic energy that is exerted on the turbine, converted to electrical energy. Betz Law states and has proved through experiments that it is almost impossible to exceed efficiencies of more than 59%. The acceptable efficiencies of wind turbine generation system are realistically in the order of 35% to 45% (EPA, 2013).

System efficiencies are lost due to a number of factors:

- Transmission losses in the gearbox;
- Pitch of the rotor blades;
- Generator efficiencies;
- Turbine miss-alignment with wind; and
- Mass of rotor blades (Al-Bahadly & Petersen et al., 2011).

The use of concentrators or diffusers can raise the efficiencies to higher levels by having the turbine mounted near the Vena Contracta (in the throat) of the diffusor assembly. This configuration is a called a Diffuser Augmented Wind Turbine (DAWT). The mass flow rate through a turbine will increase at this point when a diffuser assembly is mounted to a wind turbine. This is due to a sub-atmospheric base pressure that is created at the exit of the diffuser assembly which causes a suction effect on the assembly (Gomis et al., 2011).

It is important to note that the correct diffuser assembly is chosen for the type and size of the wind turbine. Without the outlet diffuser, the system will operate at lower efficiencies due to the increased pressure exerted on the turbine. The use of a correctly sized and designed diffuser assembly can increase the velocity through the turbine by 15%, compared to a normal free-stream system (Lawn, 2003).

Figure 2.23: Typical diffuser designs on a DAWT (courtesy of FloDesign, 2014)

The Turbine Swept Area (TSA) is the total area that is exposed to transfer the kinetic energy from the wind to the front face of the rotor blades. The center hub of the turbine also occupies some area (Hub Space) and needs to be subtracted from the total area. The power generation potential of a wind turbine is represented by the wind velocity offered over the TSA per unit of time. The energy potential can be calculated by the following equation:

Power (W) = ½ * (ρ air (kg/m^3)) * (turbine swept area (m^2)) * (wind velocity (m/sec)$)^3$ as shown in equation below.

$$\text{Power} = \frac{1}{2} * \rho * TSA * V^3$$

When installing the wind turbine within a ducted enclosure in the shape of a venturi, the acceleration of air flow at the Vena Contracta can be utilized to increase the total efficiency of the generation system. There are also no vortices present at the blade tips which will further increase the generation system efficiencies.

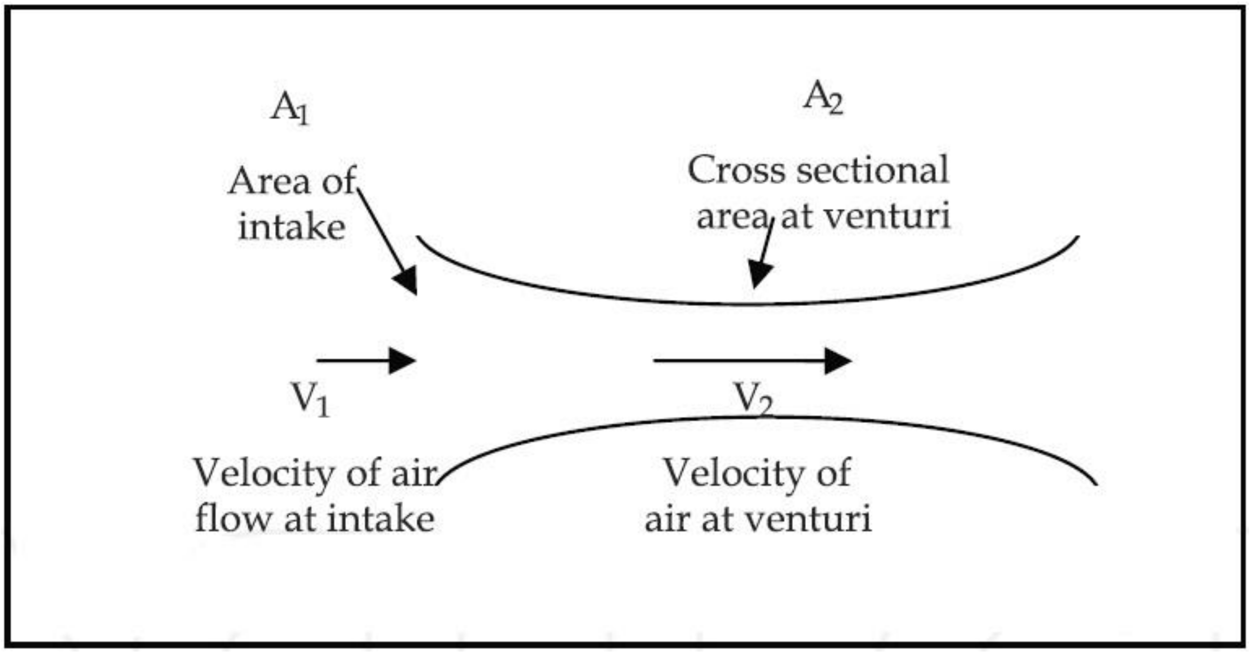


Figure 2.24: The velocity of air at the Vena Contracta of a venturi (Al-Bahadly & Petersen, 2011)

The figure above gives an indication of the accelerated flow and to calculate the new velocity at the Vena Contracta the following formulae can be used:

$$V2 = (A1 * V1)/A2$$

The total efficiencies of venturi typed ducted turbine system are in the order of 41% (Al-Bahadly & Petersen, 2011).

2.5.3.5.Resources needed

Harnessing the kinetic power from wind is very capital-intensive and there are a number of factors that will greatly influence the efficiency of the wind-turbine generation system. Most of this is covered in the previous section but, there are some geographical factors that can greatly influence the overall performance from the wind turbine system. These factors include:

- Wind direction;
- Air temperature;
- Barometric pressure;
- Vertical wind speed;
- Precipitation; and
- Most importantly; sufficient wind speed (Klickitat County, 2004).

It is thus of the utmost importance that the correct geographical location is chosen, by assessing the wind speeds and quality of the wind at the site. This will maximize the efficiency of the wind turbine system. Figure 2.25 shows an interpolated map with wind speeds recorded in South Africa.

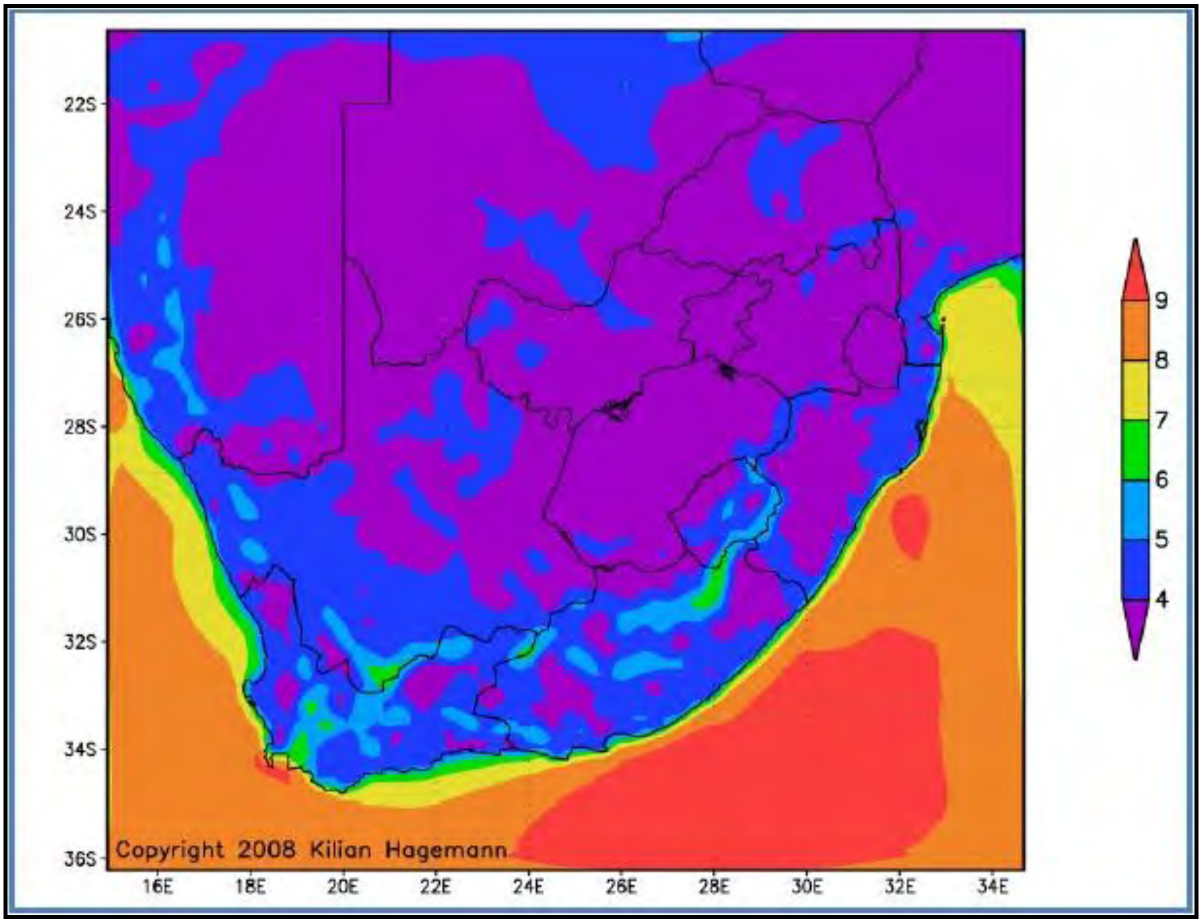
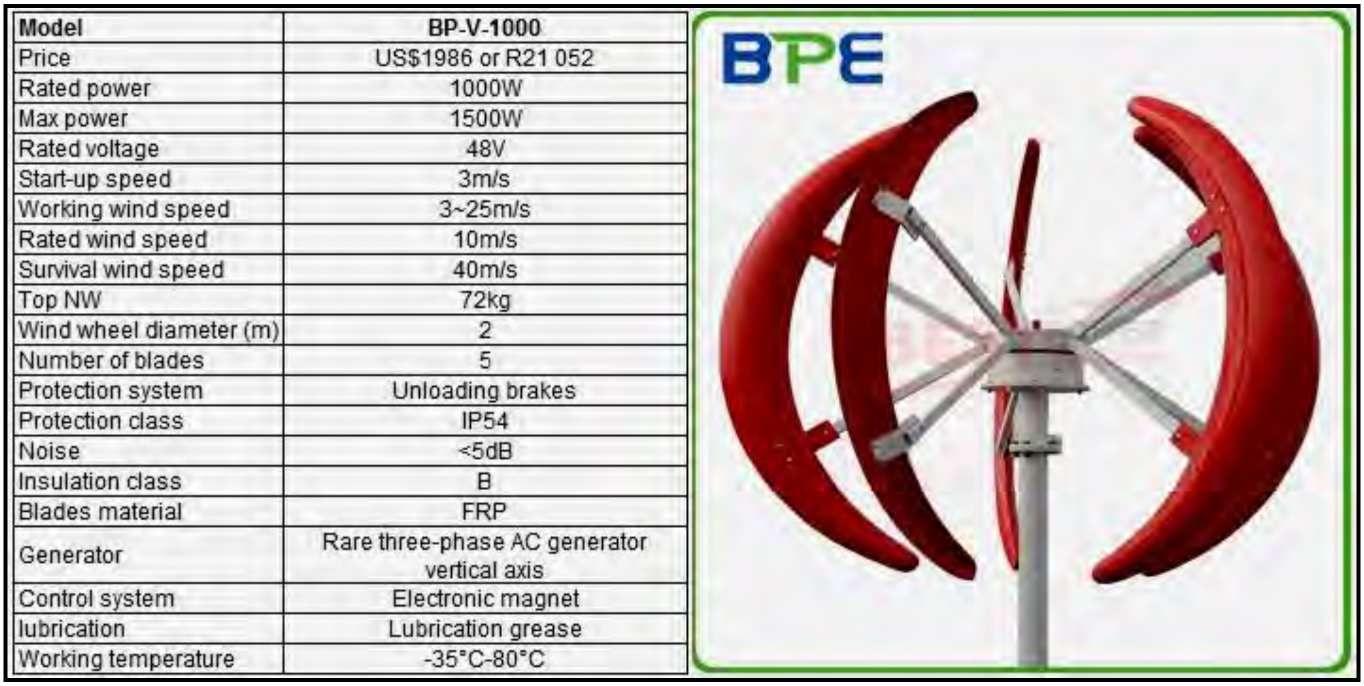


Figure 2.25: Annual average wind speed for South Africa 10m above ground level (m/s) (courtesy of Hagemann K, 2008)

Larger wind turbines generate more power, but their rotor blade spans will also increase accordingly. Careful planning must be done to ensure that land space allowance is enough to mount the wind turbines. Vertical Axis Wind Turbine’s (VAWT) require cut-in wind speeds in the order of 1.5 to 3 m/s, compared to the Horizontal Axis Wind Turbines (HAWT) which require between 2.5 to 5 m/s.



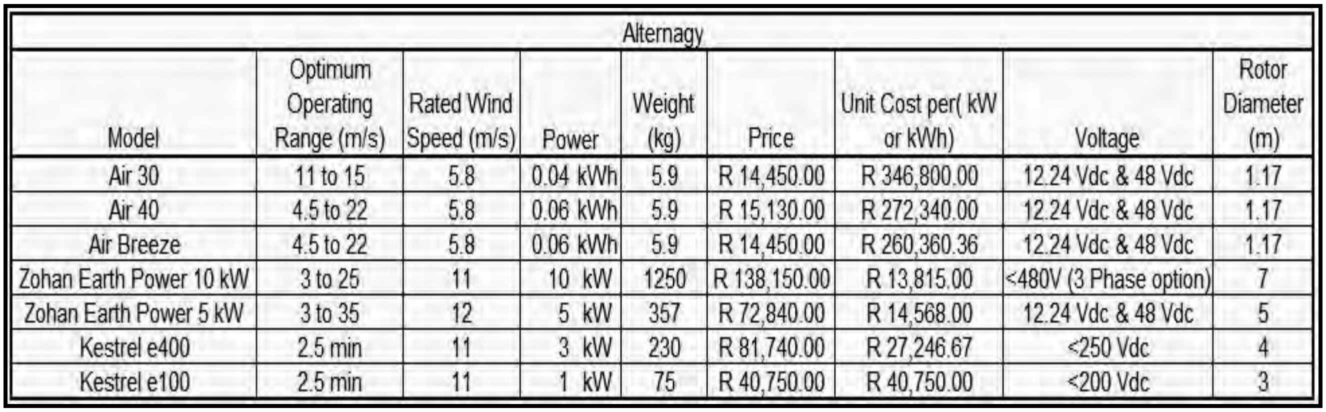
Model	BP-V-1000
Price	US$1986 or R21 052
Rated power	1000W
Max power	1500W
Rated voltage	48V
Start-up speed	3m/s
Working wind speed	3~25m/s
Rated wind speed	10m/s
Survival wind speed	40m/s
Top NW	72kg
Wind wheel diameter (m)	2
Number of blades	5
Protection system	Unloading brakes
Protection class	IP54
Noise	<5dB
Insulation class	B
Blades material	FRP
Generator	Rare three-phase AC generator vertical axis
Control system	Electronic magnet
lubrication	Lubrication grease
Working temperature	-35°C-80°C

Figure 2.26: Small VAWT unit from Best Power Energy (courtesy of ALI Express, 2014)

2.5.3.6.Cost to Produce

The cost to install large-scale wind farms will drastically reduce the cost per kW and the installed cost will be typically between USD 1000 to USD 2000 per kilowatt. These costs can be hugely influenced by the efficiency factors and geographical locations as stated above. Wind quality, location maintenance costs and manufacturing material costs will all have an influence on the costing of these power systems.

Small-scale wind-turbine power systems are more expensive and installed cost for the micro wind turbine plants will be up to USD 3000 per kW (EPA, 2013). The average cost per kW is calculated to be R24 095 per kW for the 1kW to 10 kW wind generation units supplied by Alternagy as per the table below. A VAWT unit as per figure 2.26 total cost is stated at R19, 550 (Sep 2014). Operation and maintenance costs are calculated at R300 per kW per year (NREL, 2011).



Alternagy								
Model	Optimum Operating Range (m/s)	Rated Wind Speed (m/s)	Power	Weight (kg)	Price	Unit Cost per(kW or kWh)	Voltage	Rotor Diameter (m)
Air 30	11 to 15	5.8	0.04 kWh	5.9	R 14,450.00	R 346,800.00	12.24 Vdc & 48 Vdc	1.17
Air 40	4.5 to 22	5.8	0.06 kWh	5.9	R 15,130.00	R 272,340.00	12.24 Vdc & 48 Vdc	1.17
Air Breeze	4.5 to 22	5.8	0.06 kWh	5.9	R 14,450.00	R 260,360.36	12.24 Vdc & 48 Vdc	1.17
Zohan Earth Power 10 kW	3 to 25	11	10 kW	1250	R 138,150.00	R 13,815.00	<480V (3 Phase option)	7
Zohan Earth Power 5 kW	3 to 35	12	5 kW	357	R 72,840.00	R 14,568.00	12.24 Vdc & 48 Vdc	5
Kestrel e400	2.5 min	11	3 kW	230	R 81,740.00	R 27,246.67	<250 Vdc	4
Kestrel e100	2.5 min	11	1 kW	75	R 40,750.00	R 40,750.00	<200 Vdc	3

Table 2.14: Small wind turbine costing (data sourced from Alternagy, 2014)

2.6. Chapter two - closure

Chapter two provided the literature review of all four power generation techniques currently in use for industrial sizes (100kWh and higher). The exception is made on wind-power generation which also included smaller turbine configurations. Detail on the means of operation on all four types of generation has been stipulated. This is done in order to ensure that a complete understanding is gained with regard to what resources are needed to warrant the successful usage of these generation systems.

In the next chapter, the empirical design has been developed to set the methodology and boundaries that need to be in place to gain information on the generation potential of the manufacturing facility. This chapter gave an understanding on how to complete the data acquisition from the manufacturing facility and then how to convert this information into functional data.

CHAPTER THREE

Empirical design

3.1. Chapter Three - Introduction

This chapter outlines the methodology that was used in order to conduct the research for this study. The initial part of this chapter elaborates on how the research was done in line with an acceptable data framework that fits into the Safripol operations.

The later part of this chapter provides insight into the different methods of data collection that took place as well as presenting an explanation on how the information is converted into functional data. Financial models applicable to this study are explained as well as the specific calculations that are incorporated into these models.

3.2. Safripol statistical data framework

As described in the previous chapters, Safripol consists of various manufacturing plants. All of these plants require operational processes to be controlled within specified tolerances or control limits. This requirement necessitates the accurate measurement of various critical variables and process conditions.

All raw material consumptions are measured and recorded throughout the value chain of the business. A central software data-collection process utilizes a Database Management System (DBMS) provided by Aspen Tech. This DBMS allows for data to be collected throughout the business which is stored for further use. This database provides the information inputs into all kinds of uses such as:

- Performance reporting;
- Advanced process control algorithms;
- Historical data reports; and
- Process data-trending.

The DBMS is used on Six Sigma projects where data collection needs to take place in order to establish performance baselines during the measuring phase of the Six Sigma DMAIC methodology.

For the purposes of this study the data collected on the various process data and consumption figures of utilities are extracted from the Aspen Tech System. Typical utilities which are of importance for the study include:

- Potable water consumption;
- Steam consumption;
- Electricity consumption;
- Effluent flow rates;
- Cooling water process data; and
- Exhaust gas and flare gas process variables.

Other reporting tools utilized at Safripol include data-tracking sheets, which are compiled in order to build monthly performance reports. These reports are updated and distributed to keep the production process owners informed on the performance of their associated production plants.

The performance reports provided data for use in this study which include the following:

- Production performance data;
- Raw material (Monomer) usages;
- Raw material yield figures;
- Waste production figures;
- Electricity costing figures; and
- Financial performance data.

Equipment specification files are kept in the maintenance facility to provide performance specifications on all equipment installed on the facility.

3.3. Data-collection processes

The various methods of generating alternative electrical power applicable to the Safripol facility required different means of data collection processes. Each of these means of power generation is unique and therefore the data collection processes are addressed accordingly.

3.3.1. Data collection - Solar PV generation

Physical and geographical location data were collected in order to understand the manufacturing site's orientation with the sun. This included the Zenith and Azimuth angle towards the sun which is of importance with regard to the generation capacity of the PV system.

Physical characteristics measurements of roofed buildings were obtained from detailed drawings of the buildings, in order to provide the data to calculate the area and angles of the roofed surfaces.

3.3.1.1. Capacity calculations - Solar PV-generation

Total and direct area calculations were done in order to establish the maximum capacity of the roofed buildings and structures on the manufacturing site. All possible rooftop areas are included with the exception of roofed structures in the hazardous production areas. These hazardous areas were excluded from the study because of the cost involved in classifying equipment as being explosion proof.

Direct area data are calculated by means of subtracting shaded areas from the total available area of the potential rooftop:

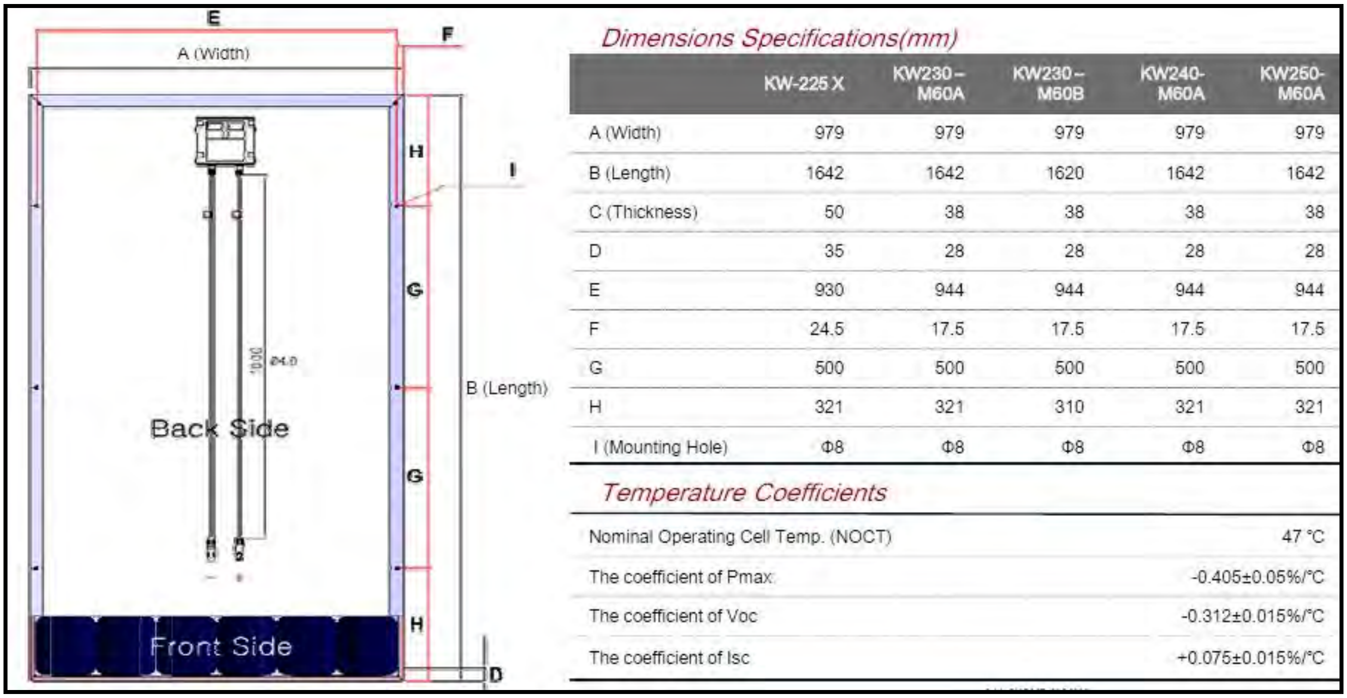
$$\textbf{Direct Area (m}^{\mathbf{2}}\textbf{)} = \text{Total area (m}^2\text{)} - \text{Shaded area (m}^2\text{)}$$

Only the direct area is used in order to calculate the potential installation space available for PV panels. The maximum generation potential is calculated by dividing the direct area with the area required, to mount one PV panel and then multiplying the total with the capacity of the panel in watt. No sun tracking systems were considered for this study due to the detrimental effects caused by the additional shading and weight that it adds to the system.

The formula that was used to calculate the generation potential of any definite area is:

Generation Potential (W_p) = (Direct Area ÷ Panel Area) x Panel Capacity (W_p)

The specific panel that was utilized in this model is a typical 250W_p PV panel supplied by *KSolar* (model no: KW250 M60A).



Dimensions Specifications(mm)

	KW-225 X	KW230 – M60A	KW230 – M60B	KW240- M60A	KW250- M60A
A (Width)	979	979	979	979	979
B (Length)	1642	1642	1620	1642	1642
C (Thickness)	50	38	38	38	38
D	35	28	28	28	28
E	930	944	944	944	944
F	24.5	17.5	17.5	17.5	17.5
G	500	500	500	500	500
H	321	321	310	321	321
I (Mounting Hole)	Φ8	Φ8	Φ8	Φ8	Φ8

Temperature Coefficients

Nominal Operating Cell Temp. (NOCT)	47 °C
The coefficient of Pmax	-0.405±0.05%/°C
The coefficient of Voc	-0.312±0.015%/°C
The coefficient of Isc	+0.075±0.015%/°C

Figure 3.1: Dimensions of a typical 250W_p PV panel (courtesy of KSolar, 2014)

The panel area amounted to 1.6m^2 as per the calculation below:

Panel Area = Length of panel x width of panel

= 0.979m x 1.642m

= **1.607 m^2**

Shaded areas were visualized by taking photos at three time intervals during a day, in mid-June, in order to fully comprehend the result of shading caused by the angle of the sun during the winter solstice. The three time intervals were:

- 08h00
- 12h00
- 16h00

The De-rate factor taken for the system was as per Chapter two, which was calculated to be 0.77 (see Table 2.2). The De-rate factor incorporates the losses occurring when converting the DC power to AC power. These losses transpire due to:

- Inverter and transformer efficiencies;
- Diode connections;
- AC and DC wiring;
- Sun tracking vs. fixed installations; and
- Soiling (dust accumulation on PV panels)

Maximum system capacity was calculated with the following formula:

Maximum capacity (W_p) = Generation potential x De-rate factor

The total time available for generation was taken from 8h00 to 16h00 which adds up to eight hours of sunlight that can be utilized for power generation. This accounts to one third of the day and was then used as one of the factors to determine the maximum annual generation capacity of any installed system.

Annual generation capacity (kWh) = Maximum capacity x 365 x 8

Power generation from Solar PV systems will not generate any form of emissions. This means that there was a cost-saving associated with the avoidance of CO-emission taxes, which in turn added to the financial benefit of the installed system. The total of emissions avoided was calculated with the following formula:

Carbon emissions avoided (kg) = Total renewable power generated (kW) x CO intensity of electricity generated in RSA (kg/kW)

The carbon intensity of electricity generation in South Africa is 0.87kg/kW. The rate at which the carbon emissions are taxed for the purposes of this study was set at R120/t. This was done to cater for the unknown increases that may occur after the year 2019 (a worst case scenario).

3.3.2. Data collection – power from hydrocarbon waste

Hydrocarbon waste figures that are reported through the Safripol utility reporting system were compiled into a single sheet that represented all waste streams. These data was represented into a weighted total that provided the opportunity to calculate the stored heat energy of the solid and liquid waste.

Heat energy values were researched and allocated to all waste streams which formed the basis to calculate the potential of the waste stream, to generate steam through a combustion system. Other forms of hydrocarbon conversion such as gasification and pyrolysis processes were not pursued in this study due to the complexity and costs involved in establishing such plants.

Hydrocarbon waste in the gaseous form was calculated from yield values obtained from the monomer report system. The yield values are reported in percentage of total gas converted into product and can therefore be accurately calculated from the total consumption of the polymerization plants. Any monomer not converted into product is accepted to be flared and thus can be considered to be waste.

3.3.2.1. Capacity calculations – power from hydrocarbon waste

All waste streams are compiled in kilograms (kg) per year and used to calculate the total heat energy in in Joule (J) per year.

Annual Heat Energy Potential (MJ) = Annual Waste Total (kg) x Heat Content (MJ/kg)

Once the Annual Heat Energy Potential (AHEP) value is calculated, the Net Heat Rate (NHR) of a Combined Heat and Power (CHP) plant was utilized to calculate the electrical energy generation potential of the specific solid and liquid waste streams.

Annual Power Generation Potential (kWh) = AHEP (MJ) ÷ NHR (MJ/kWh)

The average NHR (in J/kWh) of an electric-power generating unit is calculated by dividing the total heat input to the system (MJ/h) by the net electric power generated by the plant (in kilowatts), taking into account the boiler, turbine, and generator efficiencies and any auxiliary power requirements.

The Net Heat Rate value can be obtained from chapter 2, see table 2.6. A value of 4.819 MJ/kWh is used and calculated for CHP System 2, which has a 3000 kW generation capacity. This value was utilized for all liquid and solid waste streams.

An NHR value of 5.388 MJ/kWh (from table 2.9) was used for reciprocating generation systems to calculate the generation capacity of all gas waste streams. This value is applicable to System 4, which is also a 3000 kW system.

Hourly Generation Potential (kWh) = Annual Power Generation Potential ÷ 365÷24

Emissions emitted from combustion systems were calculated by using the emissions factors listed in table 2.7 and table 2.10 respectively. These values are presented in kg/GJ and since the total energy amounts of waste in GJ are captured, the resulting emissions can be calculated with the following formula:

Annual Emissions (kg) = Annual Waste Stream Total (GJ) x Emission Factor (kg/GJ)

The resultant total was converted into tons per annum, in order to calculate the CO taxes which were taken into consideration in the financial models.

3.3.3. Data collection – hydropower generation

The manufacturing site is not situated next to a river or stream, which means that it will not be possible to install water turbine generators that will run on large-scale water flow systems. The possibility to build a large elevated storage system is also not feasible; as such an investment requires large amounts of capital to construct the civil necessities. This means for the purpose of this study the focus is on piped and open channel water flow systems.

As a manufacturing site which makes extensive use of water in their cooling and conveying systems, the opportunity presented itself to generate electrical power from these piped systems. The investigation focused on piped water networks that are large enough to support generators of 1000W and larger.

The investigation concentrated on all water systems installed on the Sasolburg manufacturing site. Data on flow rates were captured in conjunction with the pipe or channel sizes. Where flow meters are installed the existing measurements were captured and recorded. Practical measurements were conducted with the use of a portable ultra-sonic flow meter in the case when there are no flow meters installed on the piped systems.

The line pressure inside the pipe systems was measured and recorded. The upstream head (elevation) was recorded where there is no pressure present or in the case of open channel systems. The installation of piped turbine generators leads to permanent pressure losses on the piped system. This was taken into consideration when selecting possible installation points. The permanent pressure loss in the system should not affect the rest of the Safripol operations.

Water networks that may contain debris or other solid materials were avoided since this will cause the turbine blades to become clogged and will lead to a breakdown of the generation equipment.

3.3.3.1. Capacity calculations – hydropower generation

The three variables that need to be measured in order to calculate the potential electrical power generation capacity are:

- Head in meters of the pipe/channel system (or equivalent pressure);
- Flow rate of the water (m^3/s); and
- Turbine generator efficiency (%).

The formula that was used to calculate the generation potential is:

$$\textbf{Generation Potential (kW)} = 10 \times \text{Head (m)} \times \text{Flow } (m^3/s) \times \eta$$

Power generation form a hydro-system is also considered to be a form of renewable energy generation. The total amount of CO emission avoided was calculated according to the factors used for Solar PV.

3.3.4. Data collection – wind driven power generation

Wind turbines are dependent on the amount of wind energy available to drive the blades on the turbine system. The geographical location of the manufacturing site was investigated and compared to the annual wind speed chart in figure 2.25. The geographical data were also used to determine the elevation above sea level which influenced the air density at the site of installation.

Other forms of wind or gas in motion were also investigated in order to establish what the possibilities were to install ducted wind turbine systems. Typical areas that were investigated were installations where air or gas is used in drying or conveying systems.

Wind energy is a form of kinetic energy which means that it will be dependent on the density and speed at which it moves. The density of any medium is greatly influenced by the temperature and pressure it is exposed to. For the purposes of calculating the potential kinetic energy the following variable needs to be captured:

- Wind speed or velocity (m/sec);
- Density of the medium (kg/m^3);
- Temperature variations (°C) which will influence the density;
- Pressure variations of the system (kPa) which will influence the system; and
- Area of the intake or swept area of the blades (m^2).

3.3.4.1. Capacity calculations – wind driven power generation

Where the pressure and temperature conditions are found to be stable the following formula was used to calculate the potential power generation:

$$\textbf{Power (W)} = \tfrac{1}{2} * (\rho \text{ air } (kg/m^3)) * (\text{Turbine Swept Area } (m^2)) * (\text{wind velocity } (m/sec))^3$$

$$\text{or } \textbf{Power} = \tfrac{1}{2} * \rho * TSA * V^3$$

When installing the wind turbine within a ducted enclosure in the shape of a venturi, the acceleration of air flow at the Vena Contracta can be accelerated and this was calculated according to the shape and area of the planned venturi. Wind power generation is also considered to be a form of renewable energy generation. The total amount of CO emission avoided was calculated in accordance to that of Solar PV and hydro-power.

3.4. Quality assurance of measurements

All measurements taken with the aid of installed instrumentation were verified according to the last calibration dates and certificates of the instrumentation in use. Where no instruments are installed, the use of calibrated portable instrumentation was prescribed.

If no portable measurements are possible the design specification of equipment installed was used to calculate the balance in flow inside pumped systems. This was also applicable where air blower systems were in use.

3.5. Financial analysis

All related financial models and calculations were based on the existing models and rates currently in use in the Safripol business. Carbon tax incentives were included to add value to investments where power generation techniques led to a reduction in these emissions. Where generation techniques produce additional carbon emissions, the additional taxes were added to the total cost of the installation.

3.5.1. Net Present Value (NPV)

Net present value of cash flow is one of the key decision-making tools which Safripol uses to evaluate the potential value of a capital investment. The value is calculated by using the initial capital investment (cash outflow, a negative value) and then adding the future cash inflow generated by the project which, is adjusted according to the Weighted Average Cost of Capital (WACC) of the Safripol business. The WACC value is represented as a percentage.

Discounted Cash Flow (DCF) is determined by the following formula:

$$\mathrm{DCF} = \frac{R_t}{(1+i)^t}$$

Where:

t– Represents the time of the cash inflow (year number)

i– Represents the discount rate (for Safripol this will represent the WACC) e.g. the cost of capital

R_t– Represents the net cash flow i.e. cash inflow at time *t*

The investment return in terms of discounted cash flow is calculated for each year over a period of ten years. The formula to calculate the Net Present Value is then:

$$\mathrm{NPV}(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Where:

N – Represents the number of periods to take into consideration

If the resultant NPV is positive (greater than R0) the company will embark on the investment from a financial point of view. If the NPV value is negative (less than R0) the financial motivation will falter since there is no financial benefit in this investment.

Should the NPV calculate to be equal to R0 the company may still embark on this investment but, it will not be done from a financial point of view. Other reasons or motivations such as strategic position or socio economic commitments may substitute the value created from a project with a neutral NPV.

3.5.2. Internal Rate of Return (IRR)

The internal rate of return is a measure to determine how profitable a capital investment will be for Safripol. This value is calculated by setting the NPV equal to zero. The rate on return is then calculated in order to provide the magnitude (in percentage) of the return.

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = 0$$

Where:

r - Represents the IRR value in percentage

C_n - Represents the Cash inflow

If the IRR value calculates to be bigger than the cost of capital (WACC) that applies to Safripol, the project will be considered feasible. If the IRR value calculates to be lower than the cost of capital, the project will not make financial sense, thus will be rejected by the management team. This value is also calculated for a period of ten years.

3.5.3. Profitability Index (PI)

The profitability index is a ratio factor that represents the ratio between the present value of income generated by the project and the cost of the investment. This value is a simple unit indicator used by Safripol to point out which investment will allow for the greater return, or if the business should make the investment. The PI at Safripol is calculated over a period of ten years and the decision is based on comparing the value to a ratio of one:

- PI > 1 - Will indicate that you may proceed with the investment.
- PI < 1 – Will indicated that it is not feasible to embark on the investment.

3.5.4. Simple payback period

The simple payback period is a financial mechanism used by Safripol to calculate how quickly the capital investment will be recovered from income received from the investment. This value is calculated to indicate the return time in years / months.

The recovered income from the investment does not allow for any discounts received from the capital depreciation processes, interests and taxes that may be incorporated. This method ignores the time value of income received from the investment.

3.5.5. Discounted payback

The discounted payback is a budgeting procedure that will indicate the period it will take to break even from the time of the initial capital investment. The income generated that is used for this calculation takes into consideration taxes and interests. It is therefore based on the Discounted Cash Flow that the investment will provide.

Projects that have a NPV of less than R0 will mean that the project will never be repaid. The discounted payback period is also calculated to represent the discounted payback time in years / months.

3.5.6. Depreciation calculation

The depreciation of capital investment was based on the standard five-year period currently in use by the South African Revenue Service (SARS). This entails the straight-line depreciation of 20% for the assets procured on capital investments. This applied to all non-renewable power generation techniques.

Investments done on renewable power generation techniques have the advantage to conduct the depreciation on an accelerated basis of three years. SARS stipulates the depreciation of 50% of the assets in year one, 30% in year two and the last 20% in year three. This will not have an effect on the simple payback period, but benefited the NPV, IRR and discounted payback period.

3.5.7. Weighted average cost of capital

The Weighted Average Cost of Capital (WACC) for Safripol is calculated using the following formula:

$$\text{WACC} = w_d\,(1-T)\,r_d + w_e r_e$$

Where:

w_d – Represents the debt portion of the project finance

w_e – Represents the equity portion of the project finance

r_e – Represents the cost of internal equity (Rate)

r_d – Represents the cost of debt (Rate, linked to Reserve bank prime)

T – Represents the tax rate of the company

At the time of this study the business is in the process to be re-financed which leads to the equity portion being set at 40% and the debt portion at 60%. The tax rate for the business is 28% which is in line with the SARS rates applicable to businesses for the year 2014. The cost of internal equity is 20.3% and the cost of debt is 9.25% which is the current prime rate from banking institutions (Aug 2014).

The calculated WACC for the Safripol business can therefore be calculated which provides a value of 12.12% (nominal). This value is used to calculate all other discounted financial values such as the NPV, IRR, PI and discounted payback period.

3.5.8. Project economic viability criteria

The economic viability of any capital investment that will take place at Safripol depended on the following financial decision making mechanisms:

- NPV –must be more than R0.
- IRR – must be more than the WACC (12.12% nominal).
- PI – must be greater than 1.
- Discounted payback period – must be less than 10 years.

If a project adheres to the above-mentioned criteria, it is considered feasible for the Safripol shareholders to embark on the capital investment. The different power generation techniques were subjected to these criteria in order to establish the most financially favourable generation technique for the Safripol business.

3.6. Method of statistical data processing

The empirical investigation profoundly depended on the theoretical calculations of capacities and costing indicators, by making use of the formulas presented in this chapter. This is primarily due to the absence of financial funding to embark on practical experiments with expensive power-generation equipment.

All data were captured into Excel work sheets to represent the data in table and graph format. All formulas were entered into the Excel programs which conducted the capacity and financial calculations automatically.

3.7. Chapter three - closure

Chapter three presented all the means that were followed to capture and analyse the related data in accordance with systems that are in use at Safripol. The formulas to calculate the capacities and financial returns have been stated. The next chapter provides the results from the empirical investigation. All generation possibilities were identified and investigated in accordance with all the stated requirements listed in chapter two.

CHAPTER FOUR

Results

4.1. Chapter Four - Introduction

This chapter provides practical insight into the various opportunities that Safripol possesses in order to support alternative power generation. The chapter is arranged according to the research topics covered in chapter 2. Each of the power generation techniques will be used as a primary output; in order to investigate the unused resources which the facility retains that can act as an input into the power generation technique.

The second part of this chapter presents the financial results. The Safripol electricity charging programme is presented which will act as the primary denominator in order to calculate the financial results. Other benefits such as carbon tax reductions will be incorporated in the results.

4.2. Solar PV generation

4.2.1. Required resources - Summarized

The major resources required for solar photovoltaic power generation are:

- Land space
- Irradiance from the sun - sunlight
- Capital investment

Chapter two provides some detailed specifications with regard to installations done in the USA that gives a relation to what capacity of power can be generated to the land space that the array will occupy.

It is of importance to note the geological location of the array site in order to maximize the efficiency of the PV system. Shaded areas should be avoided as it will negatively impact on the total generation of the system.

Solar PV power is still considered to be capital intensive to install but the system allows for modular installation, dividing the total system up into smaller less costly installations. This will allow for savings on power to fund the next phase of installation.

4.2.1.1. Land space

Safripol is a Polymer producer that caters mainly for the South African market. This means that the marketing strategy of the business is aligned to cater for smaller niche customers which provide a bigger return on the product sold. The downfall of this marketing strategy is having larger stock levels of finished product but it also provides timely deliveries and improved customer service.

Figure 4.1: Aerial view of warehouse system (courtesy of Google Earth, 2014)

Larger stock levels of finished product requires big warehouse systems of which Safripol has a total of six warehouses (A to G) that cover a total area of 4.01 hectares. Warehouse E is a sub-divided section of warehouses B, C and D.

Warehouse A to warehouse D were constructed in 1970 and the design incorporated inclined shed roof design facing to the northern side of the factory. Figure 4.1 illustrates the view of the warehouse system and car-ports.

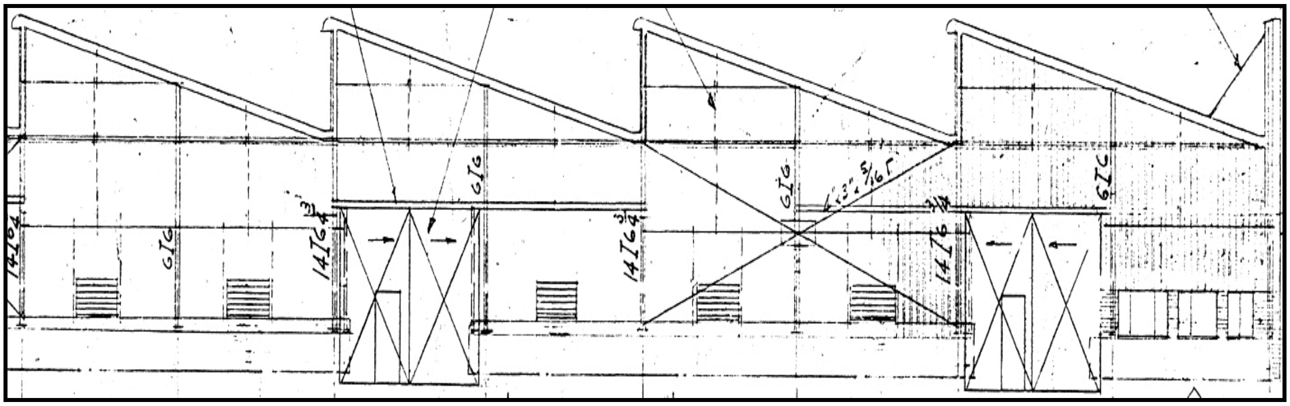
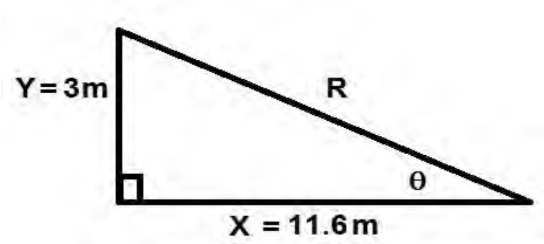


Figure 4.2: Warehouses A to D shed-type roof design

The shed-type design is repeated four times (as seen in figure 4.2) for each warehouse; this means that Warehouse A is divided into four separate warehouses namely A1, A2, A3 and A4. The incline angle and width of the inclined roof cover are not present on the detail drawings but can be calculated from the available dimensions given on the original design drawing:



Where $\mathbf{R^2 = X^2 + Y^2}$

$$\mathbf{= (11.6^2 + 3^2)^{-2}}$$

$$\mathbf{R = 11.98\ m}$$

The incline angle of the shed design can be calculated using the Sine function and the lengths of the sides that form a right triangle:

Where $\mathbf{\sin\theta = Y \div R}$

$$\mathbf{\theta = Sin\text{-}1\ (3 \div 11.98)}$$

$$\mathbf{\theta = 14.50°}$$

The warehouses F and G were added in the late 1990s and early 2000s respectively and the roof design was totally different from the rest of the warehouses. These two warehouses are fitted with a gable-type roof structure design. Warehouse F center frame faces East/West and warehouse G's centre frame is aligned to face North/South.

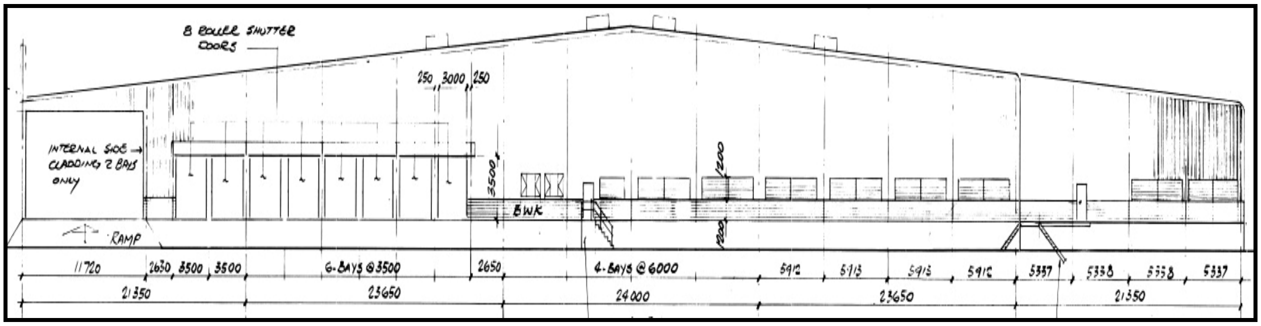


Figure 4.3: Warehouse F Gable roof design

The roof structure of Warehouse F is set at an angle of 3° and therefore it can almost be considered as a flat type roof which ensures that there are no shadows cast on the southern side of the roof. This is not the case for Warehouse G of which is situated to the eastern side of Warehouse D and the design angle of the centre structure is done at an angle of 13° which causes shadows to fall on the roof of the side that faces east.

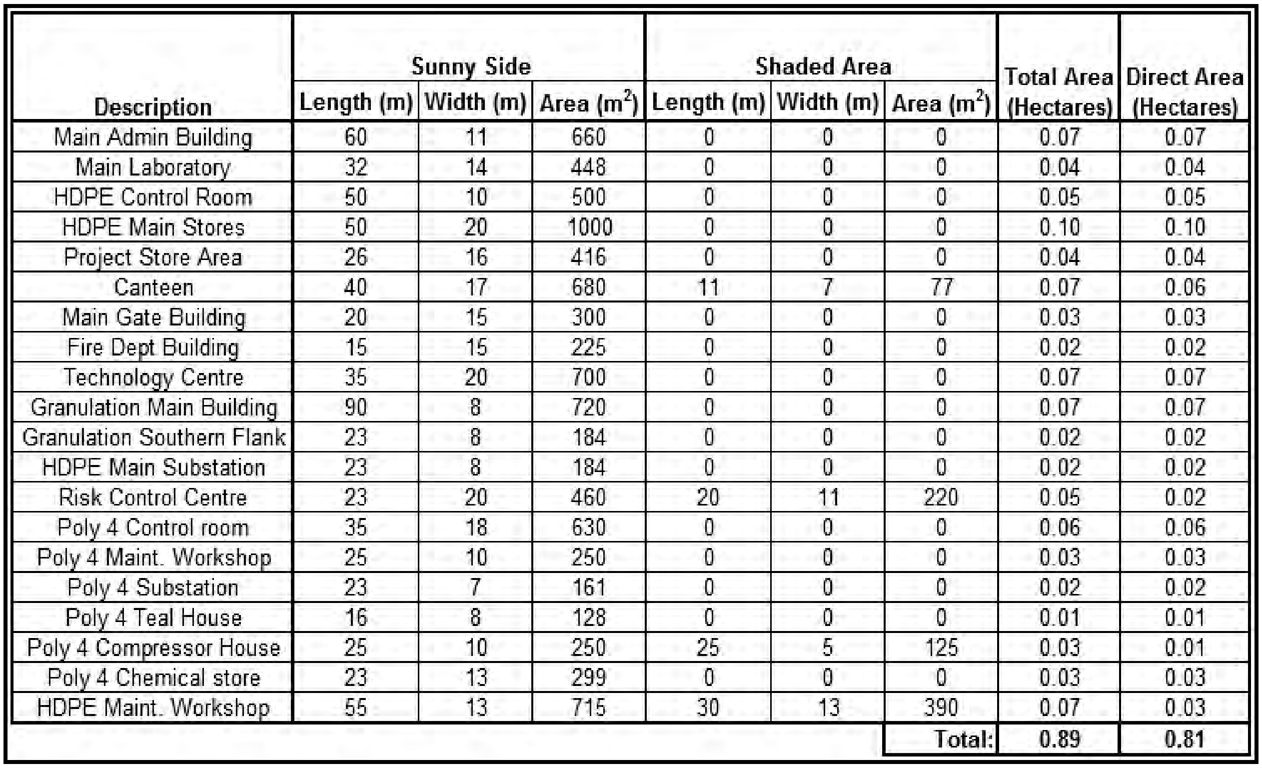
Description	Sunny Side			Shaded Area			Total Area (Hectares)	Direct Area (Hectares)
	Length (m)	Width (m)	Area (m^2)	Length (m)	Width (m)	Area (m^2)		
Warehouse A1	100	12	1200	80	12	960	0.12	0.02
Warehouse A2	100	12	1200	80	12	960	0.12	0.02
Warehouse A3	100	12	1200	80	12	960	0.12	0.02
Warehouse A4	100	12	1200	80	12	960	0.12	0.02
Warehouse B1	130	12	1560	130	5	650	0.16	0.09
Warehouse B2	130	12	1560	130	5	650	0.16	0.09
Warehouse B3	130	12	1560	130	5	650	0.16	0.09
Warehouse B4	130	12	1560	130	5	650	0.16	0.09
Warehouse C1	130	12	1560	130	5	650	0.16	0.09
Warehouse C2	130	12	1560	130	5	650	0.16	0.09
Warehouse C3	130	12	1560	130	5	650	0.16	0.09
Warehouse C4	130	12	1560	130	5	650	0.16	0.09
Warehouse D1	130	12	1560	130	5	650	0.16	0.09
Warehouse D2	130	12	1560	130	5	650	0.16	0.09
Warehouse D3	130	12	1560	130	5	650	0.16	0.09
Warehouse D4	130	12	1560	130	5	650	0.16	0.09
Warehouse F	130	114	14820	0	0	0	1.48	1.48
Warehouse G	90	20	1800	90	10	900	0.18	0.09
						Total:	4.01	2.76

Table 4.1: Total land space of Safripol warehouse system

The two production facilities are controlled from dedicated control rooms and the plants are supported with maintenance workshops and a central main spare-parts store. Other buildings on the production site include:

- Electrical sub-stations
- Laboratory
- Administrative building
- Fire & Risk control stations
- Technology centre
- Chemical storage

Table 4.2 provides the detail area calculations that include all major roofed buildings amounting to a total area of 0.89 hectares.

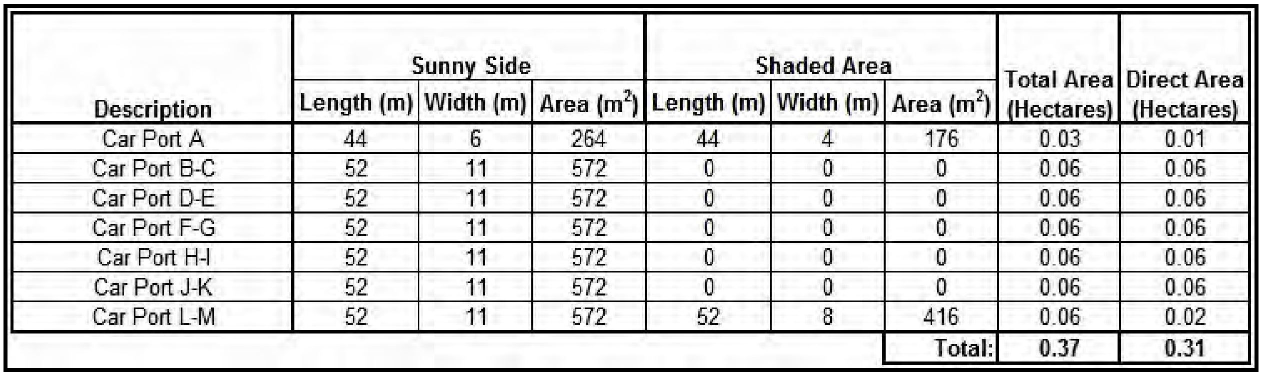


Description	Sunny Side			Shaded Area			Total Area (Hectares)	Direct Area (Hectares)
	Length (m)	Width (m)	Area (m^2)	Length (m)	Width (m)	Area (m^2)		
Main Admin Building	60	11	660	0	0	0	0.07	0.07
Main Laboratory	32	14	448	0	0	0	0.04	0.04
HDPE Control Room	50	10	500	0	0	0	0.05	0.05
HDPE Main Stores	50	20	1000	0	0	0	0.10	0.10
Project Store Area	26	16	416	0	0	0	0.04	0.04
Canteen	40	17	680	11	7	77	0.07	0.06
Main Gate Building	20	15	300	0	0	0	0.03	0.03
Fire Dept Building	15	15	225	0	0	0	0.02	0.02
Technology Centre	35	20	700	0	0	0	0.07	0.07
Granulation Main Building	90	8	720	0	0	0	0.07	0.07
Granulation Southern Flank	23	8	184	0	0	0	0.02	0.02
HDPE Main Substation	23	8	184	0	0	0	0.02	0.02
Risk Control Centre	23	20	460	20	11	220	0.05	0.02
Poly 4 Control room	35	18	630	0	0	0	0.06	0.06
Poly 4 Maint. Workshop	25	10	250	0	0	0	0.03	0.03
Poly 4 Substation	23	7	161	0	0	0	0.02	0.02
Poly 4 Teal House	16	8	128	0	0	0	0.01	0.01
Poly 4 Compressor House	25	10	250	25	5	125	0.03	0.01
Poly 4 Chemical store	23	13	299	0	0	0	0.03	0.03
HDPE Maint. Workshop	55	13	715	30	13	390	0.07	0.03
						Total:	0.89	0.81

Table 4.2: Total land space of Safripol roofed buildings

The site is equipped with a roofed car-port where all the employees can park their vehicles during the time spent at work. There are a total of seven roofed car-ports that covers a total area of 0.37 hectares. Table 4.3 provides the detail area calculations for these car-ports.

The roof design of the car-ports is also a shed type design with the slope facing north but the incline is almost negligible due the small angle that it forms and can therefore almost be considered to be a flat roof type.



Description	Sunny Side			Shaded Area			Total Area (Hectares)	Direct Area (Hectares)
	Length (m)	Width (m)	Area (m^2)	Length (m)	Width (m)	Area (m^2)		
Car Port A	44	6	264	44	4	176	0.03	0.01
Car Port B-C	52	11	572	0	0	0	0.06	0.06
Car Port D-E	52	11	572	0	0	0	0.06	0.06
Car Port F-G	52	11	572	0	0	0	0.06	0.06
Car Port H-I	52	11	572	0	0	0	0.06	0.06
Car Port J-K	52	11	572	0	0	0	0.06	0.06
Car Port L-M	52	11	572	52	8	416	0.06	0.02
						Total:	**0.37**	**0.31**

Table 4.3: Total land space of Safripol roofed car-ports

4.2.1.2. Irradiance

The geographical setting of the manufacturing site is in Sasolburg, which is a small town in the northern part of the Free State Province, South Africa. According to the horizontal irradiance chart data provided in Chapter 2 this region will have an annual average of 2000 kWh/m^2.

The co-ordinates of the manufacturing site are: 26°48’16”S & 27°51’51” E. This indicates that the ideal tilt angle for Solar PV panels must be between 10 to 15 degrees plus the latitude, which is 26°. This adds up to an ideal tilt angle of 36 to 41 degrees to maximize the efficiency from the PV panels that are to be installed at this site.

Shaded areas will negatively influence the efficiency of the PV panels and must be avoided when designing array systems. Safripol as a site is built with a number of high structures such as storage silos that cast long shadows over various buildings for long durations of daytime. The buildings that are affected by these shadows are listed in Tables 4.1, Table 4.2 and Table 4.3.

Figure 4.4: Top view of Warehouse C at 08h00

Tests were conducted at the site at three time intervals in order to establish the impact that shadows will have on the separate building structures. These tests were conducted during the winter solstice to ensure that the unfavourable effect of the sun (shading) during the winter months was captured to its full extent.

From figure 4.4 we can see that at 08h00 in the morning the shadows caused by the shed roof design cause the blocking of almost half of the sunlight on Warehouses B to D. The shadows are reduced as the sun moves higher into the sky and from figure 4.5 and figure 4.6 we can see that less than 20% of the roofs are shaded between 12h00 and 16h00.

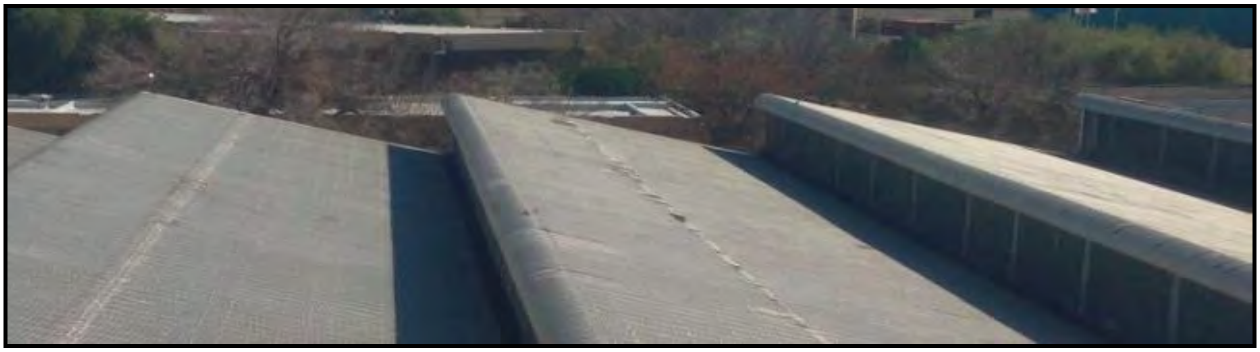


Figure 4.5: Top view of Warehouse C at 12h00

Figure 4.6: Top view of Warehouse C at 16h00

Figure 4.7: Warehouse G at 16h00

Warehouse G is situated on the eastern side of the warehouses and as listed in the table 4.1, it is shaded for large parts of the day. Warehouse F is by far the most illuminated of all the warehouses and from figure 4.8 it can be seen that this roof is not shaded at all between 08h00 and 16h00. This is due to the flat roof design and orientation of the warehouse.

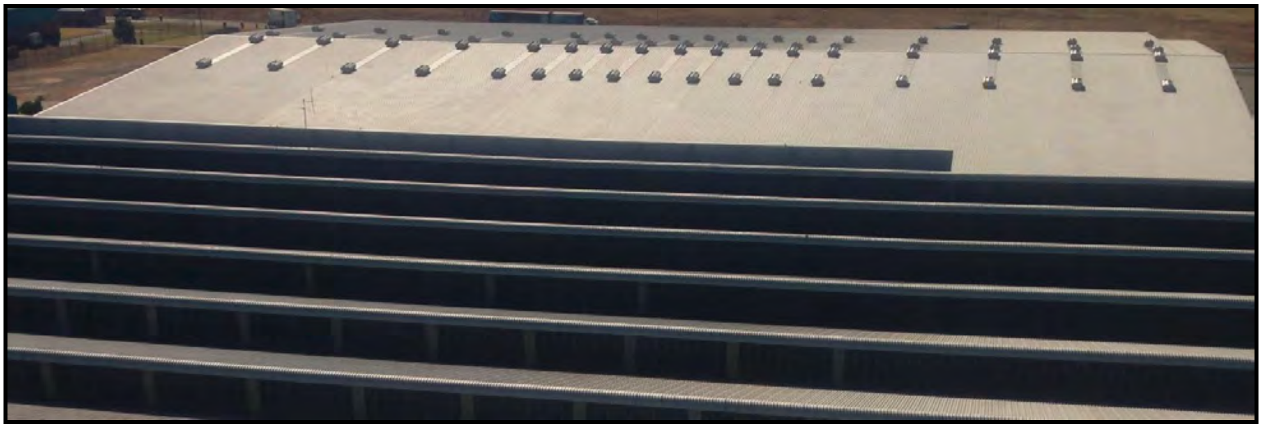


Figure 3.8: Warehouse F at 12h00

Other buildings have been investigated and the shaded portions have been added up and presented in terms of shaded area calculations in tables 4.1 to 4.3. This included the car-ports where much of the shading is caused by large trees.

4.2.2. Safripol PV generation potential

In total the land space that Safripol has available for the installation of PV panels, is calculated to be 5.27 hectares. As discussed in the paragraphs above, some portions of buildings are not suited to be fitted with PV panels due to shading that occurs at certain times of the day.

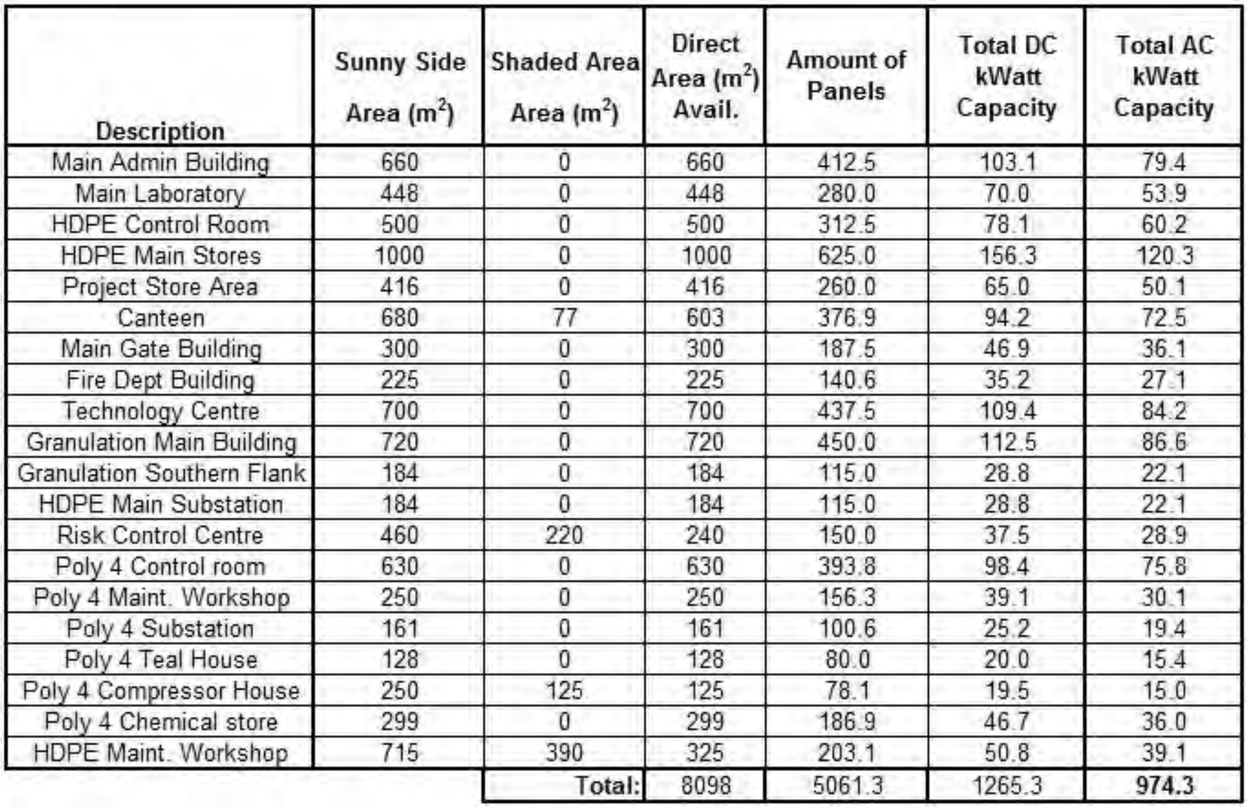
The shaded areas have been calculated and amounted to 1.39 hectares, leaving a total of 3.88 hectares (or 38 800 m^2) open for utilization for PV power-generation. This figure represents the direct-area available for PV generation.

The following tables contain data using the area calculated in tables 4.1 to 4.3. The direct area (Total Area less Shaded Area) is used in order to calculate the number of panels that can be fitted onto the calculated direct area. The area requirements and specifications are based on a KW250 M60A PV panel supplied by *KSolar* as per Annexure A.

The three buildings that provide the largest potential for solar PV power generation are:

i. HDPE Main Stores;
ii. Granulation Main Building; and
iii. Technology Centre.

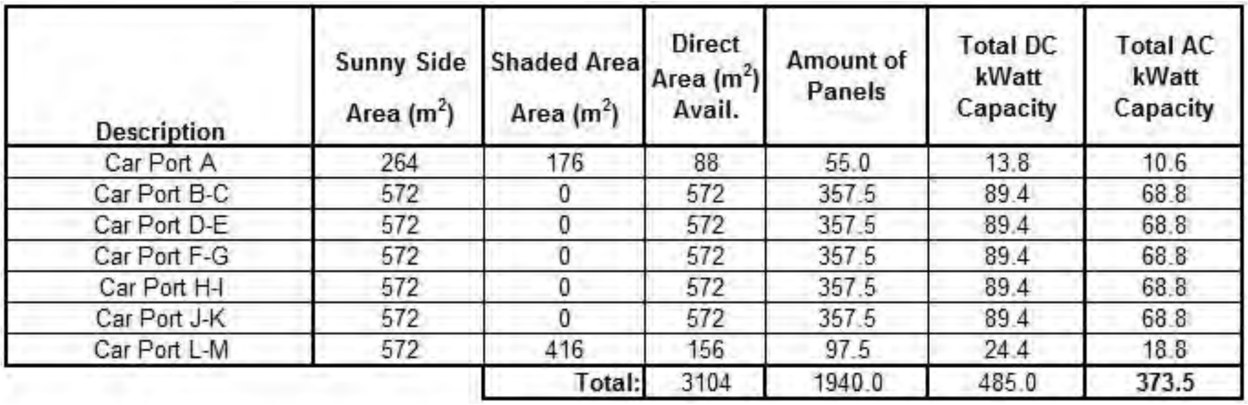
Other buildings that offer some noticeable generation possibilities are the Main Administration building as well as the Poly 4 Control room.



Description	Sunny Side Area (m^2)	Shaded Area Area (m^2)	Direct Area (m^2) Avail.	Amount of Panels	Total DC kWatt Capacity	Total AC kWatt Capacity
Main Admin Building	660	0	660	412.5	103.1	79.4
Main Laboratory	448	0	448	280.0	70.0	53.9
HDPE Control Room	500	0	500	312.5	78.1	60.2
HDPE Main Stores	1000	0	1000	625.0	156.3	120.3
Project Store Area	416	0	416	260.0	65.0	50.1
Canteen	680	77	603	376.9	94.2	72.5
Main Gate Building	300	0	300	187.5	46.9	36.1
Fire Dept Building	225	0	225	140.6	35.2	27.1
Technology Centre	700	0	700	437.5	109.4	84.2
Granulation Main Building	720	0	720	450.0	112.5	86.6
Granulation Southern Flank	184	0	184	115.0	28.8	22.1
HDPE Main Substation	184	0	184	115.0	28.8	22.1
Risk Control Centre	460	220	240	150.0	37.5	28.9
Poly 4 Control room	630	0	630	393.8	98.4	75.8
Poly 4 Maint. Workshop	250	0	250	156.3	39.1	30.1
Poly 4 Substation	161	0	161	100.6	25.2	19.4
Poly 4 Teal House	128	0	128	80.0	20.0	15.4
Poly 4 Compressor House	250	125	125	78.1	19.5	15.0
Poly 4 Chemical store	299	0	299	186.9	46.7	36.0
HDPE Maint. Workshop	715	390	325	203.1	50.8	39.1
		Total:	8098	5061.3	1265.3	**974.3**

Table 4.4: Generation capacity of Safripol roofed buildings

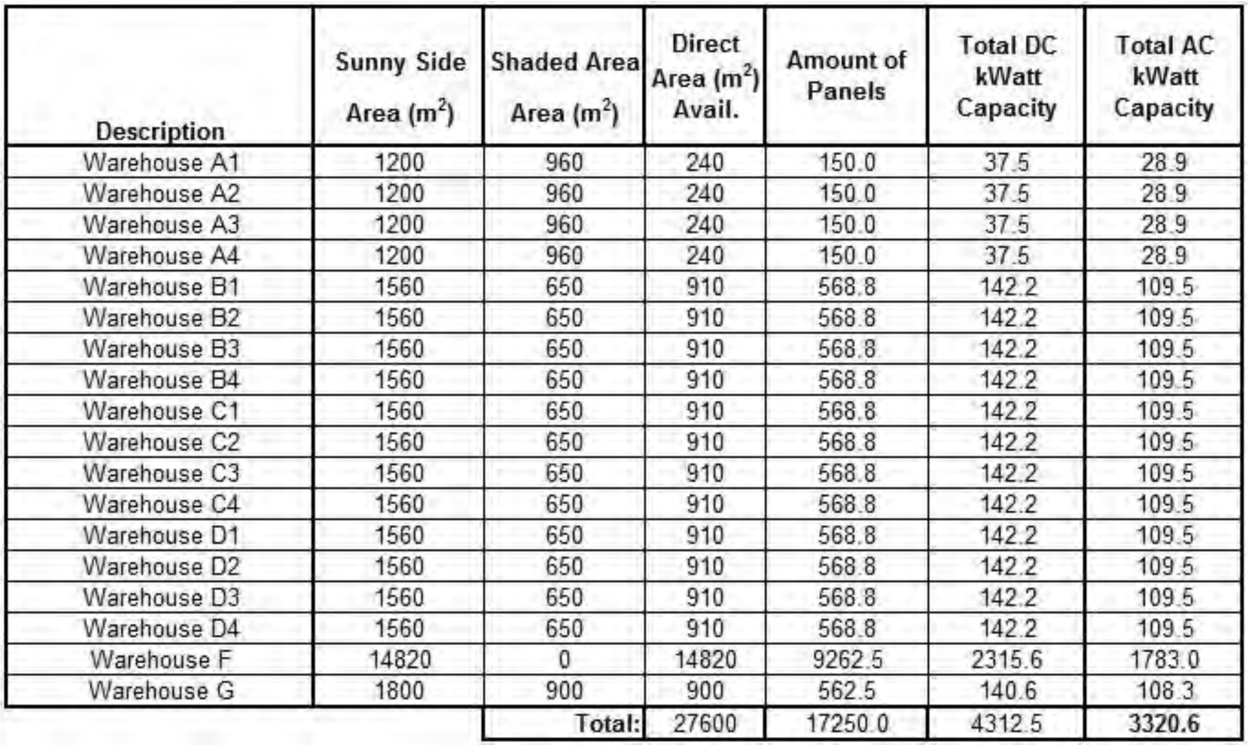
The car ports also provide significant generation possibilities adding up to a total of 373.5 kilo Watt AC. Apart from car-port A and car port L-M, all other car ports experience maximum exposure to sunlight with no shading that takes place for the duration from 8h00 to 16h00.



Description	Sunny Side Area (m^2)	Shaded Area Area (m^2)	Direct Area (m^2) Avail.	Amount of Panels	Total DC kWatt Capacity	Total AC kWatt Capacity
Car Port A	264	176	88	55.0	13.8	10.6
Car Port B-C	572	0	572	357.5	89.4	68.8
Car Port D-E	572	0	572	357.5	89.4	68.8
Car Port F-G	572	0	572	357.5	89.4	68.8
Car Port H-I	572	0	572	357.5	89.4	68.8
Car Port J-K	572	0	572	357.5	89.4	68.8
Car Port L-M	572	416	156	97.5	24.4	18.8
		Total:	3104	1940.0	485.0	**373.5**

Table 4.5: Generation capacity of Safripol car- ports

The largest potential is the warehouse system which in total can be fitted with 17250 panels which will provide a generation capacity of 3.32 Mega Watt AC power.



Description	Sunny Side Area (m^2)	Shaded Area Area (m^2)	Direct Area (m^2) Avail.	Amount of Panels	Total DC kWatt Capacity	Total AC kWatt Capacity
Warehouse A1	1200	960	240	150.0	37.5	28.9
Warehouse A2	1200	960	240	150.0	37.5	28.9
Warehouse A3	1200	960	240	150.0	37.5	28.9
Warehouse A4	1200	960	240	150.0	37.5	28.9
Warehouse B1	1560	650	910	568.8	142.2	109.5
Warehouse B2	1560	650	910	568.8	142.2	109.5
Warehouse B3	1560	650	910	568.8	142.2	109.5
Warehouse B4	1560	650	910	568.8	142.2	109.5
Warehouse C1	1560	650	910	568.8	142.2	109.5
Warehouse C2	1560	650	910	568.8	142.2	109.5
Warehouse C3	1560	650	910	568.8	142.2	109.5
Warehouse C4	1560	650	910	568.8	142.2	109.5
Warehouse D1	1560	650	910	568.8	142.2	109.5
Warehouse D2	1560	650	910	568.8	142.2	109.5
Warehouse D3	1560	650	910	568.8	142.2	109.5
Warehouse D4	1560	650	910	568.8	142.2	109.5
Warehouse F	14820	0	14820	9262.5	2315.6	1783.0
Warehouse G	1800	900	900	562.5	140.6	108.3
		Total:	27600	17250.0	4312.5	**3320.6**

Table 4.6: Generation capacity of Safripol warehouse system

The total area that a typical 250Wp mono-crystalline panel consumes is ±1.6m^2. In theory it means that Safripol can install approximately 24 250 panels, which can generate a maximum peak DC system power of 6062.5 kW. The de-rate factor to invert DC power to AC power is set at 0.77. This represents total AC power at 4.668 MW peak.

4.3. Electricity generation from hydrocarbon waste

4.3.1. Required resources - summarized

Steam generators for use with steam turbines and internal combustion engines are designed to run on a variety of hydrocarbon-based fuel options. The design and construction of these types of power generation units are capital-intensive and require careful design to cater for the variety of fuels that may be utilized.

The waste that could be utilized as fuel must be flammable and will need careful preparation to remove the non-flammable wastes. This process often requires additional resources. These generation techniques also lead to exhaust gases and solid residues that will require treatment before they are discharged or disposed.

4.3.1.1. Fuel requirements

Solid waste streams must be treated and dehydrated to ensure that combustion is maximized. Liquid waste fuel that is used must be filtered and may require mixing with standard fuels.

For steam generators fuel options include:

- Municipal waste;
- Hydrocarbon-based solid waste with high BTU qualities;
- Hydrocarbon-based liquid waste with high BTU qualities;
- Hydrocarbon-based flue gases;
- Syngas gas or processed fuel gas extracted directly from gasification; and
- Industrial waste gases, which are deemed to be flared.

For internal combustion generators fuels include:

- Liquefied Petroleum Gas (LPG), which contain mixes of propane and butane;
- Bio-fuel gas, any of the combustible gases produced from the organic degradation process which includes mainly methane;
- Syngas gas or processed fuel gas extracted directly from gasification; and

- Industrial waste gases, which are deemed to be flared.

4.3.2. Safripol hydrocarbon waste streams

The polymerization processes are optimized extensively to ensure that all raw materials procured are converted into final product. The plants run at total monomer yields in excess of 98.5%, which imply that very little scrap or waste is produced. The total production of the plants adds up to more than 250 kilo-tons of polymers per annum, and although the yield percentages are very good, the waste and off-spec material accounts for a noteworthy number.

The hydrocarbon waste produced can be classified into three categories:

- Waste in liquid phase arrangement.
- Waste in solid phase arrangement.
- Waste in gas phase arrangement.

Used lubricant oils that are used in gearboxes and rotating equipment is collected and stored in the oil storage yard which is also disposed of by means of third-party oil recyclers. Other liquid hydrocarbon waste includes liquid waste that is mixed with sludge which is fed via separating tubs to T6002 (a sludge waste-bin) where it is stored until disposal. Contaminated mineral oils that were utilized at the polypropylene production facility is collected in drums and prepared for removal by third-party vendors.

Liquid-waste water contains polymer particles and other contaminants such as oils and greases. This is captured in run-off channels that feed sludge pits where the solid waste is separated from the liquids. The solid waste is then manually extracted and put into waste skips which in turn are disposed of by means of a third party waste disposal company.

Solid hydrocarbon waste includes:

- Refuse or municipal waste,

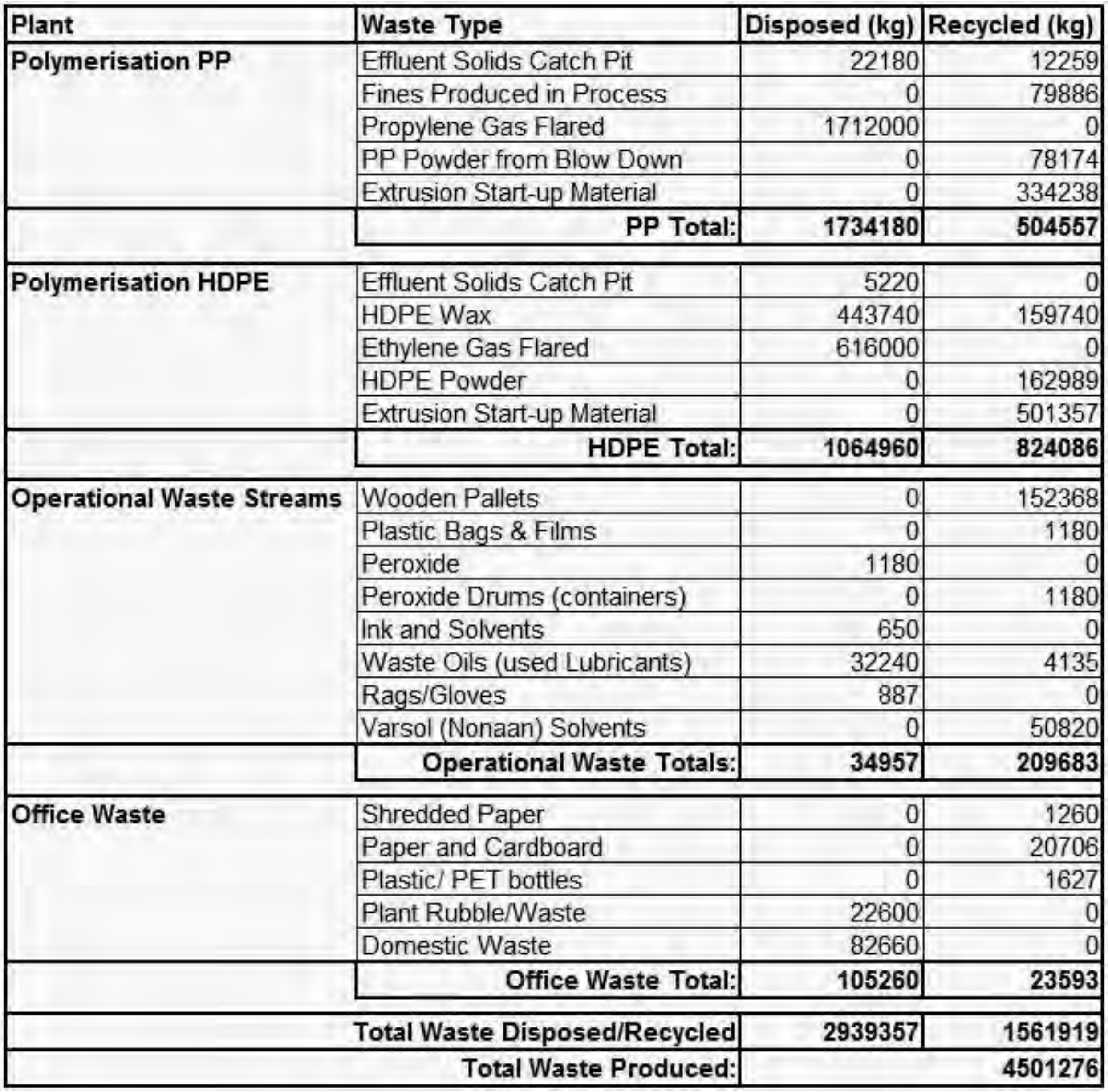
- Polyethylene wax,
- Polymer waste retrieved from the sludge water pits,
- Off-grade polymer product and polymer waste that are produced during the start-up sequences of the plants.

Off-grade material that is produced during grade-change sequences will be omitted from this study due to the fact that the material is still traded off at reduced prices.

Polyethylene (PE) wax is a by-product produced by the HDPE facility. A portion of the wax is fed back to the polymerization process to act as a natural lubricant according to customer specification but, more than 443 tons of wax is still disposed of at a relative cost to the company.

Fines and waste powder produced from the two polymerization plants are mostly recycled through the use of recycle vendors and in some cases also include associated disposal costs. This provides an ideal opportunity to reduce other waste treatment costs.

Office waste materials that are due for disposal to municipal waste sites include burnable materials such as plastic bottles, paper and other domestic wastes. Although the BTU values for these materials are not as high compared to the operational and polymerization units, they still add up to over 105 tons of burnable waste material over a period of twelve months.



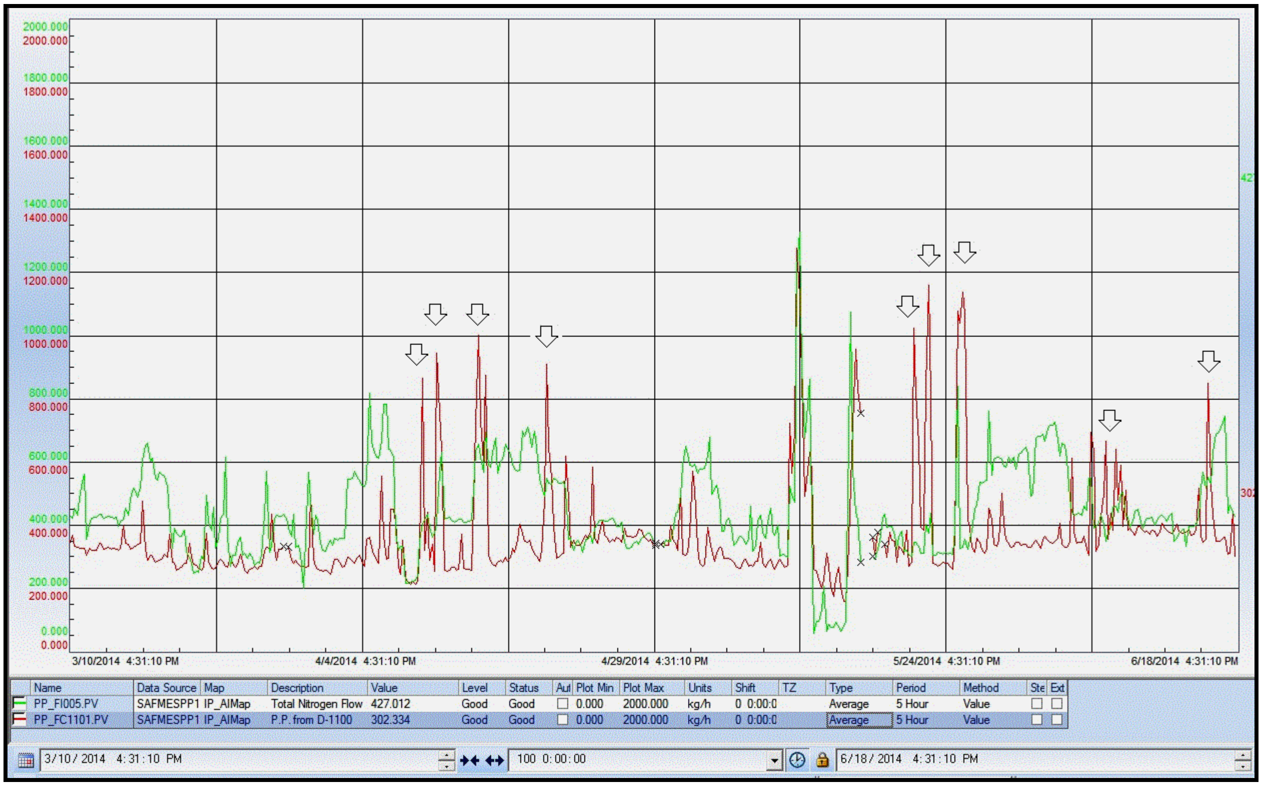
Plant	Waste Type	Disposed (kg)	Recycled (kg)
Polymerisation PP	Effluent Solids Catch Pit	22180	12259
	Fines Produced in Process	0	79886
	Propylene Gas Flared	1712000	0
	PP Powder from Blow Down	0	78174
	Extrusion Start-up Material	0	334238
	PP Total:	**1734180**	**504557**
Polymerisation HDPE	Effluent Solids Catch Pit	5220	0
	HDPE Wax	443740	159740
	Ethylene Gas Flared	616000	0
	HDPE Powder	0	162989
	Extrusion Start-up Material	0	501357
	HDPE Total:	**1064960**	**824086**
Operational Waste Streams	Wooden Pallets	0	152368
	Plastic Bags & Films	0	1180
	Peroxide	1180	0
	Peroxide Drums (containers)	0	1180
	Ink and Solvents	650	0
	Waste Oils (used Lubricants)	32240	4135
	Rags/Gloves	887	0
	Varsol (Nonaan) Solvents	0	50820
	Operational Waste Totals:	**34957**	**209683**
Office Waste	Shredded Paper	0	1260
	Paper and Cardboard	0	20706
	Plastic/ PET bottles	0	1627
	Plant Rubble/Waste	22600	0
	Domestic Waste	82660	0
	Office Waste Total:	**105260**	**23593**
	Total Waste Disposed/Recycled	**2939357**	**1561919**
	Total Waste Produced:		**4501276**

Table 4.7: Safripol annual waste stream totals

Hydrocarbon waste gases are burned through flare systems at both the PP and HDPE production facilities. Flaring does not form part of normal operations and flaring of any hydrocarbons is avoided at all costs. Flaring only occurs during plant upsets and unplanned shut-downs in order to ensure the safe shut-down of the production facilities. This implies that flaring is only taking place in unforeseen circumstances and cannot always be predicted and planned.

Figure 4.9 provides an illustration of the unpredicted flaring that typically takes place at the production facilities. The arrows (red peaks) indicate where the hydrocarbon flow exceeded the nitrogen flow at the flare-stack of the PP production facility. From the figure it is clear that hydrocarbon flaring only took place on nine occasions from March 2014 to June 2014.

This sporadic flaring is present in both the PP and the HDPE facility and when selecting flare gas recovery systems this irregular flow streams must be kept in mind, particularly in sizing and selecting the appropriate recycling compressors.



	Name	Data Source	Map	Description	Value	Level	Status	Aut	Plot Min	Plot Max	Units	Shift	TZ	Type	Period	Method	Ste	Ext
🟩	PP_FI005.PV	SAFMESPP1	IP_AIMap	Total Nitrogen Flow	427.012	Good	Good	☐	0.000	2000.000	kg/h	0 0:00:0		Average	5 Hour	Value	☐	☐
🟥	PP_FC1101.PV	SAFMESPP1	IP_AIMap	P.P. from D-1100	302.334	Good	Good	☐	0.000	2000.000	kg/h	0 0:00:0		Average	5 Hour	Value	☐	☐

3/10/ 2014 4:31:10 PM
100 0:00:00
6/18/ 2014 4:31:10 PM

Figure 4.9: Flaring peaks for 100 days at the PP plant (10 Mar 2014 to 18 Jun 2014)

The monomer yield for the PP production facility for the year 2013 was 98.4% and the total monomer that was procured for polymer production totaled 107 kilo-tons. The yield factor therefore indicates a total of 1712 tons of propylene gas that were flared in 2013.

The monomer yield for the HDPE production facility for the year 2013 was 99.6% and a total of 154 kilo-ton of ethylene gas was procured to manufacture HPDE polymer. The total amount of ethylene gas that was flared amounted to 616 tons, for the year 2013.

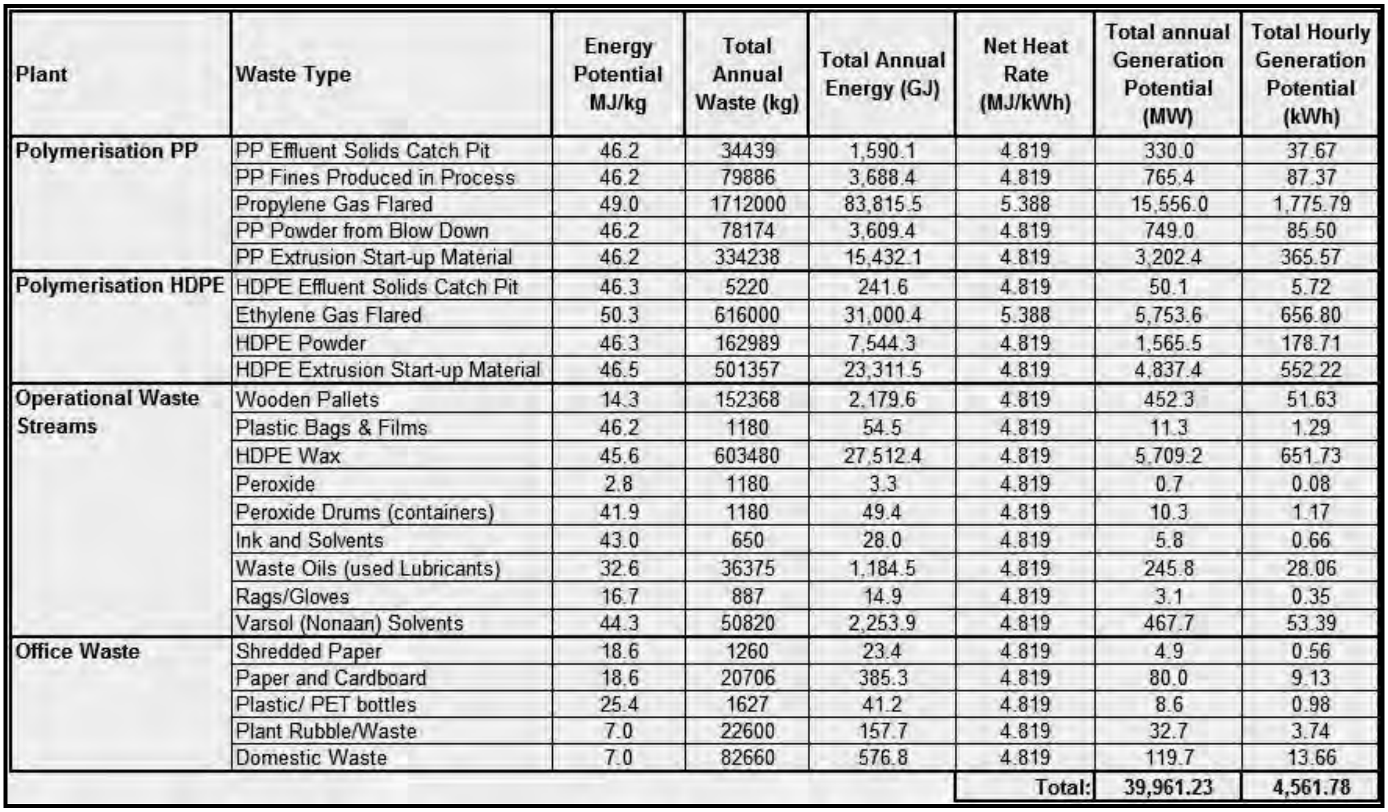
Although the calculated hydrocarbon based gases flared at the facility adds up to a total of 2328 tons of highly flammable gas, the requirements to store or facilitate these amounts of gases will require further capital investment

4.3.3. Safripol generation potential

The total waste streams data have been tabled below (table 4.8) complete with the gross combustion values (annualized in GJ) for each material included in the Safripol waste stream. The Net Heat Rate is used to calculate the total generation potential of the waste material and the values for this have been taken from the data provided in chapter two.

Waste material to be incinerated, in order to generate steam as the driving force for turbine-type generators, compare in capacity to the System 2 presented in Table 2.6 Therefore the Net Heat Rate used for the calculation was selected to be 4819 kJ/kWh.

Fuel gases that could drive internal combustion generators are the flared gas streams on both plants. The applicable Net Heat Rate value was taken from Table 2.9 which represents System 4 in the table (5388 kJ/kWh).



Plant	Waste Type	Energy Potential MJ/kg	Total Annual Waste (kg)	Total Annual Energy (GJ)	Net Heat Rate (MJ/kWh)	Total annual Generation Potential (MW)	Total Hourly Generation Potential (kWh)
Polymerisation PP	PP Effluent Solids Catch Pit	46.2	34439	1,590.1	4.819	330.0	37.67
	PP Fines Produced in Process	46.2	79886	3,688.4	4.819	765.4	87.37
	Propylene Gas Flared	49.0	1712000	83,815.5	5.388	15,556.0	1,775.79
	PP Powder from Blow Down	46.2	78174	3,609.4	4.819	749.0	85.50
	PP Extrusion Start-up Material	46.2	334238	15,432.1	4.819	3,202.4	365.57
Polymerisation HDPE	HDPE Effluent Solids Catch Pit	46.3	5220	241.6	4.819	50.1	5.72
	Ethylene Gas Flared	50.3	616000	31,000.4	5.388	5,753.6	656.80
	HDPE Powder	46.3	162989	7,544.3	4.819	1,565.5	178.71
	HDPE Extrusion Start-up Material	46.5	501357	23,311.5	4.819	4,837.4	552.22
Operational Waste Streams	Wooden Pallets	14.3	152368	2,179.6	4.819	452.3	51.63
	Plastic Bags & Films	46.2	1180	54.5	4.819	11.3	1.29
	HDPE Wax	45.6	603480	27,512.4	4.819	5,709.2	651.73
	Peroxide	2.8	1180	3.3	4.819	0.7	0.08
	Peroxide Drums (containers)	41.9	1180	49.4	4.819	10.3	1.17
	Ink and Solvents	43.0	650	28.0	4.819	5.8	0.66
	Waste Oils (used Lubricants)	32.6	36375	1,184.5	4.819	245.8	28.06
	Rags/Gloves	16.7	887	14.9	4.819	3.1	0.35
	Varsol (Nonaan) Solvents	44.3	50820	2,253.9	4.819	467.7	53.39
Office Waste	Shredded Paper	18.6	1260	23.4	4.819	4.9	0.56
	Paper and Cardboard	18.6	20706	385.3	4.819	80.0	9.13
	Plastic/ PET bottles	25.4	1627	41.2	4.819	8.6	0.98
	Plant Rubble/Waste	7.0	22600	157.7	4.819	32.7	3.74
	Domestic Waste	7.0	82660	576.8	4.819	119.7	13.66
					Total:	**39,961.23**	**4,561.78**

Table 4.8: Safripol waste to energy total potential (2013)

When the data in the table above are studied we can conclude that the operational plants are the biggest source of hydrocarbon waste. The total generation capacity for the site adds up to 4.56 MW per hour.

In the figure below, the waste type is represented in the red bars which give an indication of the combustion capacity in BTU/lbs and the blue bars represent the quantity of the specific waste type that is available on an annual basis.

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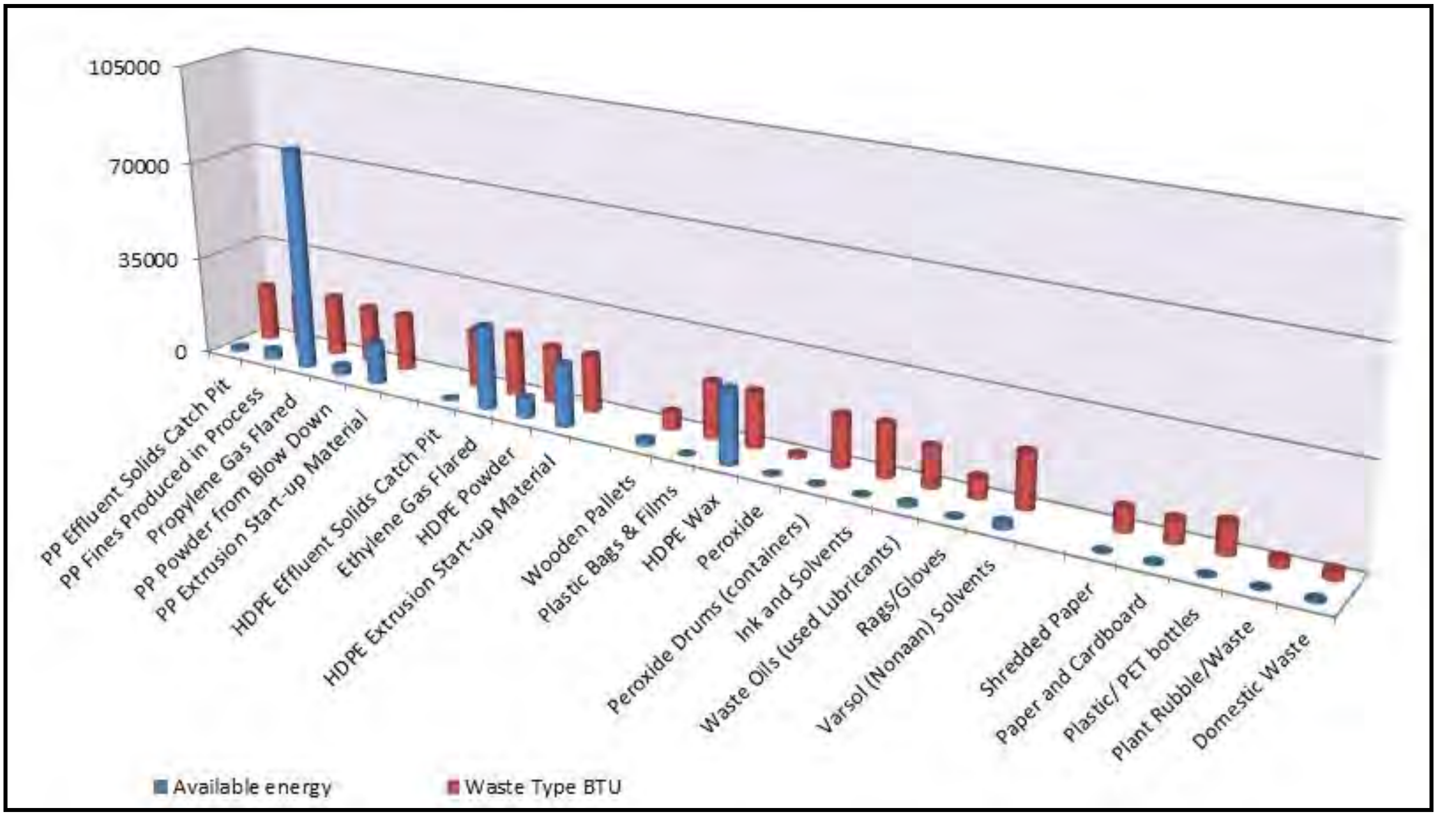


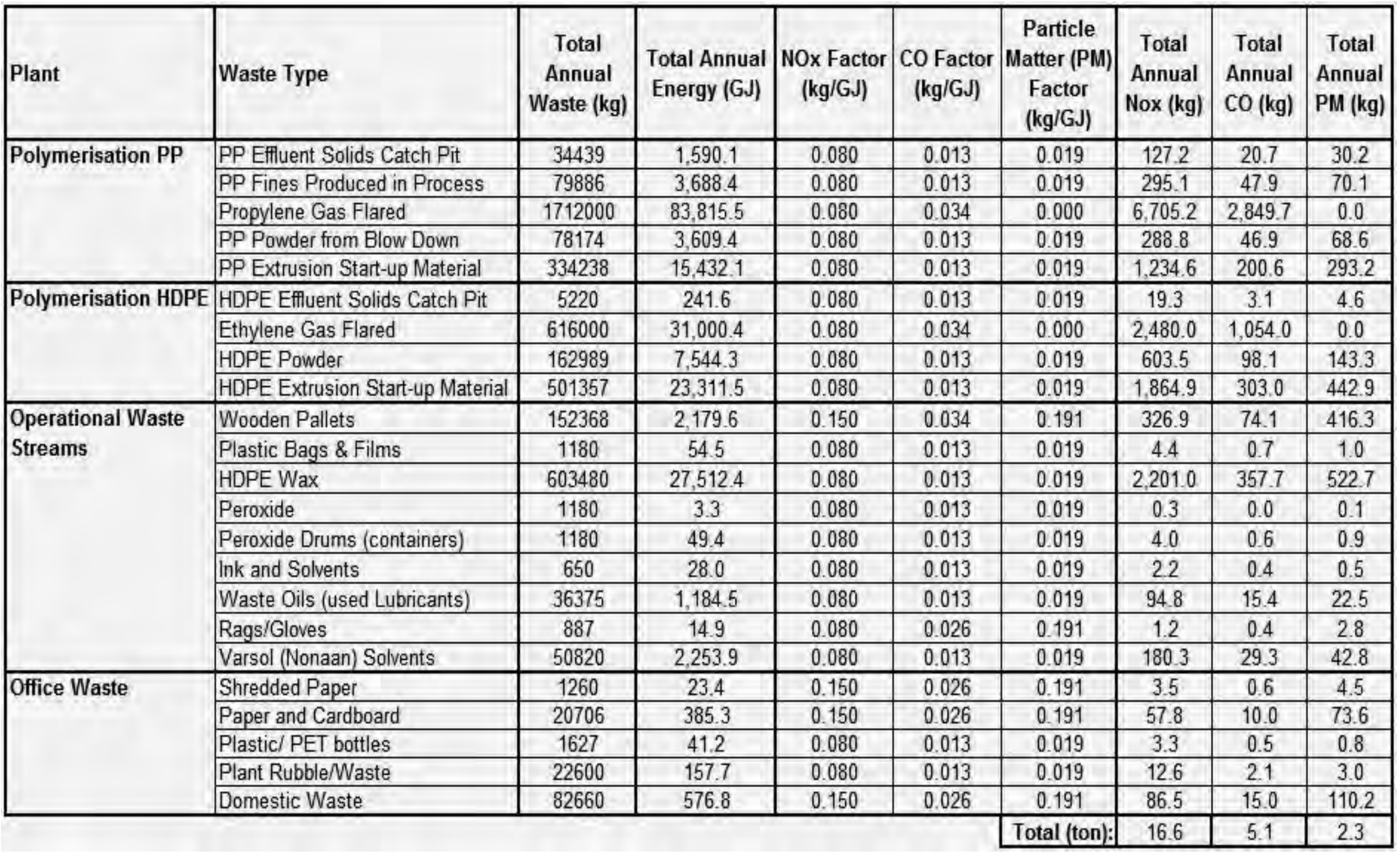
Figure 4.10: Safripol waste streams energy potential in MMBTU per annum (2013)

The graph above portrays the waste streams with the largest generation potential which are:

- Propylene gas flared;
- Ethylene gas flared;
- HDPE Wax;
- HDPE extrusion start-up material; and
- PP extrusion start-up material.

Power generation through incineration and combustion techniques will lead to emissions such as carbon monoxide, nitrogen oxide and solid particulate matter. The removal of ash and solid waste from the incineration process will require disposal resources. Currently Safripol are paying to dispose of the process waste materials which are classified as chemical waste. This is very costly and consequently any other waste disposal costs that are associated with the incineration and combustion processes will be omitted from this study.

The total air emissions are in fact a new source of pollution and will lead to additional taxes. The totals are listed in the table below.



Plant	Waste Type	Total Annual Waste (kg)	Total Annual Energy (GJ)	NOx Factor (kg/GJ)	CO Factor (kg/GJ)	Particle Matter (PM) Factor (kg/GJ)	Total Annual Nox (kg)	Total Annual CO (kg)	Total Annual PM (kg)
Polymerisation PP	PP Effluent Solids Catch Pit	34439	1,590.1	0.080	0.013	0.019	127.2	20.7	30.2
	PP Fines Produced in Process	79886	3,688.4	0.080	0.013	0.019	295.1	47.9	70.1
	Propylene Gas Flared	1712000	83,815.5	0.080	0.034	0.000	6,705.2	2,849.7	0.0
	PP Powder from Blow Down	78174	3,609.4	0.080	0.013	0.019	288.8	46.9	68.6
	PP Extrusion Start-up Material	334238	15,432.1	0.080	0.013	0.019	1,234.6	200.6	293.2
Polymerisation HDPE	HDPE Effluent Solids Catch Pit	5220	241.6	0.080	0.013	0.019	19.3	3.1	4.6
	Ethylene Gas Flared	616000	31,000.4	0.080	0.034	0.000	2,480.0	1,054.0	0.0
	HDPE Powder	162989	7,544.3	0.080	0.013	0.019	603.5	98.1	143.3
	HDPE Extrusion Start-up Material	501357	23,311.5	0.080	0.013	0.019	1,864.9	303.0	442.9
Operational Waste Streams	Wooden Pallets	152368	2,179.6	0.150	0.034	0.191	326.9	74.1	416.3
	Plastic Bags & Films	1180	54.5	0.080	0.013	0.019	4.4	0.7	1.0
	HDPE Wax	603480	27,512.4	0.080	0.013	0.019	2,201.0	357.7	522.7
	Peroxide	1180	3.3	0.080	0.013	0.019	0.3	0.0	0.1
	Peroxide Drums (containers)	1180	49.4	0.080	0.013	0.019	4.0	0.6	0.9
	Ink and Solvents	650	28.0	0.080	0.013	0.019	2.2	0.4	0.5
	Waste Oils (used Lubricants)	36375	1,184.5	0.080	0.013	0.019	94.8	15.4	22.5
	Rags/Gloves	887	14.9	0.080	0.026	0.191	1.2	0.4	2.8
	Varsol (Nonaan) Solvents	50820	2,253.9	0.080	0.013	0.019	180.3	29.3	42.8
Office Waste	Shredded Paper	1260	23.4	0.150	0.026	0.191	3.5	0.6	4.5
	Paper and Cardboard	20706	385.3	0.150	0.026	0.191	57.8	10.0	73.6
	Plastic/ PET bottles	1627	41.2	0.080	0.013	0.019	3.3	0.5	0.8
	Plant Rubble/Waste	22600	157.7	0.080	0.013	0.019	12.6	2.1	3.0
	Domestic Waste	82660	576.8	0.150	0.026	0.191	86.5	15.0	110.2
						Total (ton):	16.6	5.1	2.3

Table 4.9: Emission totals from incineration and combustion processes

4.4. Water driven turbine generators

4.4.1. Required resources - summarized

Hydro-power generation will require kinetic energy in the form of flowing water to act as the driving force on the turbines. This can be acquired from water streams that flow in rivers systems, sea currents or piped networks.

Hydro-power generation is one of the most capital-intensive means of power generation when it comes to the initial construction of civil work related to the small to large hydro-power generation plants. The scope for Safripol will, however, not involve the installation of such large generation units. This is due to the geographical location of the manufacturing site which is not situated next to a river, dam or ocean.

The installation cost to install mini- and micro-generation plants is not that capital intensive compared to a larger power generation units, and require only to be piped into existing pipe networks. This allows for the minimum civil construction work required. The total capital cost to procure such units are still expensive though with the cost per kilo Watt still in the region of R22,600 for micro-generators with a capacity of 30kW.

4.4.2. Safripol hydro-kinetic systems

The manufacturing site consumes water for uses that include sanitation, human consumption, cooling applications, heating applications, and transport of product. Potable water is procured from the local municipality, through a piped network, which is the primary means of water supply to the facility.

Other water supplies to the facility include back-up fire water supply from Natref (a neighbouring company). Back-up cooling water is supplied from Rand Water Board, which is used to supplement the cooling and fire water systems in case of emergencies only. During the normal operation of the facility these supply networks (from Natref and

Rand Water Board) are isolated from the main water supply network and will therefore be excluded from this study.

4.4.2.1. Safripol supply and effluent water

The manufacturing plants utilize water throughout most of the manufacturing process but the plant design ensures that all off the water is cleaned and re-used. Therefore very little water is wasted into effluent channels.

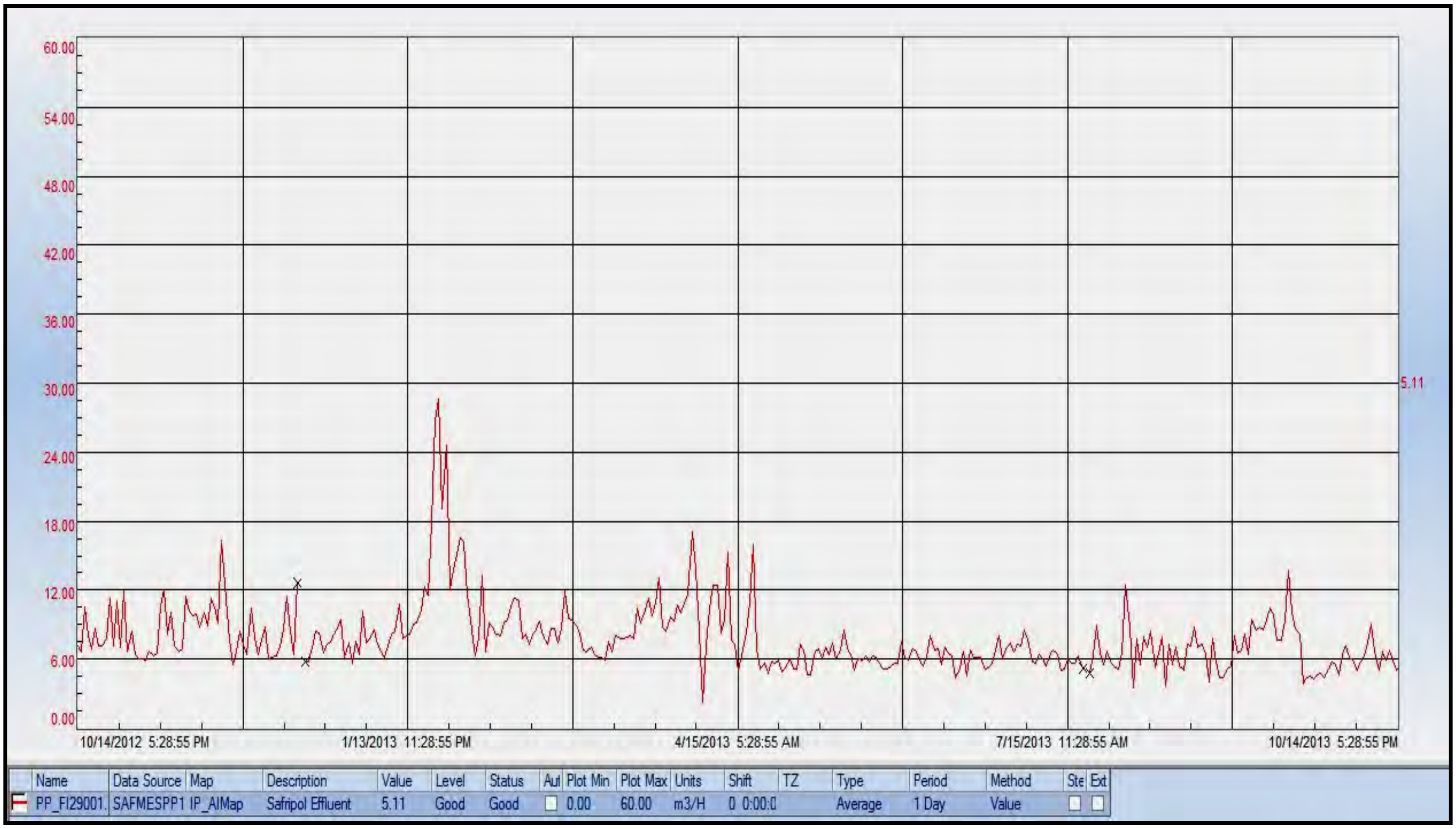
The majority of water lost in the system is caused by evaporation in the three cooling towers in use on the facility. The confirmed total supply flow of potable water averages around 54 m^3/h. Other water losses consist of water through the sewerage system and water to the garden for irrigation.

Steam is used as the major heating source to heat water streams where required by the processes. This process causes condensation of steam that converts to excess water produced, which ends up in the recycled water streams. Taking all this into account, it is clear that there is not a huge amount of water that is lost to the effluent waste system.

Effluent is present though, as water is used to clean the production plants of dirt and dust that accumulate on structures. The cleaning processes include the cleaning of vessels before any statuary inspections and preventive maintenance can be done. The vessels then need to be drained and dried before putting the vessels back into operation.

This water is channeled to the sludge water collection pits where the water is cleansed before disposal to the effluent system. The sludge-handling system then allows for a constant flow of waste water to the effluent dams. From here the water is treated by a third party, before complete disposal of the water.

During the rainy season the plant's designed rain water run-off also adds to the effluent system and peaks of such flows can be seen in the graph below.



	Name	Data Source	Map	Description	Value	Level	Status	Aut	Plot Min	Plot Max	Units	Shift	TZ	Type	Period	Method	Ste	Ext
	PP_FI29001.	SAFMESPP1	IP_AIMap	Safripol Effluent	5.11	Good	Good	☐	0.00	60.00	m3/H	0 0:00:0		Average	1 Day	Value	☐	☐

Figure 4.11: Safripol effluent water from the site (Oct 2012 to Oct 2013)

The average flow through the effluent system averages between 5-7 m^3/h which is not really enough to support any form of piped hydro-power generation system.

4.4.2.2. Cooling-tower systems

The manufacturing plants utilize water in all their cooling systems. These cooling systems form a closed loop back to the cooling towers from where it is supplied. The two production facilities for HDPE and PP each has their own dedicated cooling towers and the granulation plant shares one cooling towers set with the HDPE production facility. There are three cooling tower systems for the facility each with their own sand filter systems to clean the associated water which are in continuous operation all of the time.

The PP plant's cooling system supply consists of three centrifugal pumps capable of delivering 1200 m^3/h each. During normal operation two pumps are running continuously with one pump on stand-by. The total flow through this system is calculated to be at 2200 m^3/h.

The sand filter system is done by running an 8" piped loop system back to the towers from the supply side of the pumps. The flow through the PP sand filter is set to run at 105 m^3/h.

The cooling system at the HDPE facility is done with two cooling-tower systems, one that is dedicated to the HDPE facility and one bigger cooling tower system shared with the granulation plant. The dedicated system for the HDPE facility is similar to the cooling-tower system in use at the PP plant. Both cooling systems use the same pump configuration, delivering a calculated flow of 2200 m^3/h to a section of the HDPE facility.

The sand filter system for HDPE also obtains its supply from the pump supply header, back to the return line which is 4" in diameter. The flow through this filter is set at 130 m^3/h.

The cooling tower system for granulation and a portion of HDPE consists of five pumps in total. Four pumps are running continuously delivering a flow of 5000 m^3/h. The return lines of these plants all converge into a single return pipe which can be utilized for pipe hydro-power generation.

Figure 4.12: HDPE/Granulation plant cooling tower with sand filter system

The sand filter system for HDPE/granulation obtains its supply from the supply line and then feed to the cooling towers utilizing an 8” pipe. The flow through this filter is set at 157m^3/h.

4.4.2.3.Transport water systems

The granulation plant consists of seven extruder lines which utilize water as a cooling/transport medium in order to complete the granulation process. The transport water is a closed loop system that operates completely independently from the rest of the cooling water systems.

The transport water is stored in tanks, from where the water is heated and fed to the cutter-heads of the extruders. The water cools the extruded plastic inside the cutter head and from there the water acts as a transport medium for the granules produced. A liquid/solid separator splits the granule stream from the water. From the separator outlet the water is fed back to the storage tank.

The transport water is pumped to the extruder but from the separators and dryers the water is fed back through gravitational force only into the Contra-sheer. The storage tanks and pumps are located on the ground floor of the plant. The extruders (except Line 7) and separators are located on the first floor of the plant which accommodates the gravitational flow of water back to the tanks.

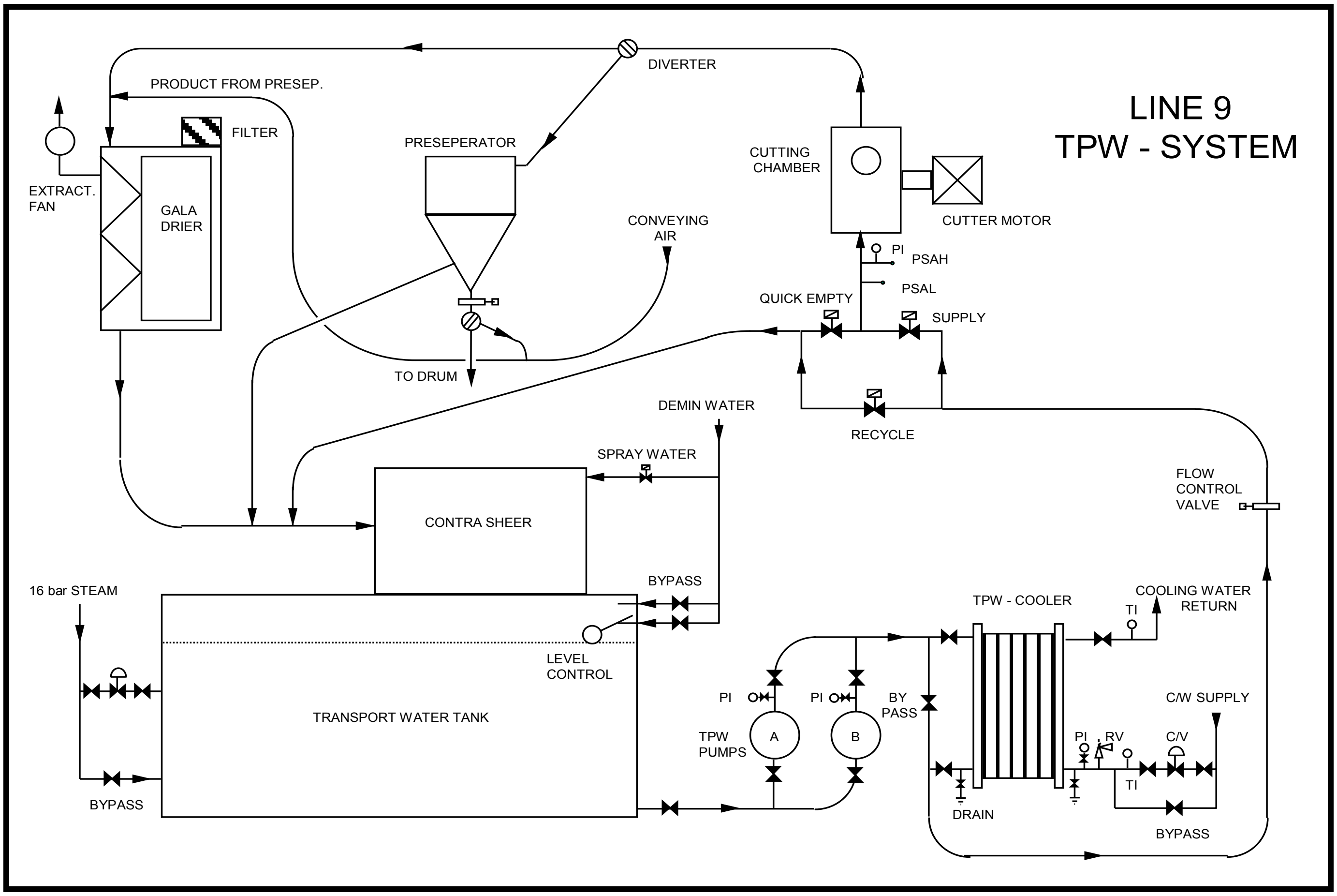


Figure 4.13: Extruder transport water system

These return flow lines are then free from any granules and can therefore be utilized to host piped hydro-power generators. It must be taken into consideration that the extruder lines are not running all of the time due to line shut-downs occurring due to breakdowns and the availability of product to be extruded.

4.4.3. Safripol hydro-power generation potential

The table below contains all the related flow streams as discussed in the paragraphs above. The flows have been either measures or calculated from the pump deliveries and associated pump curves.

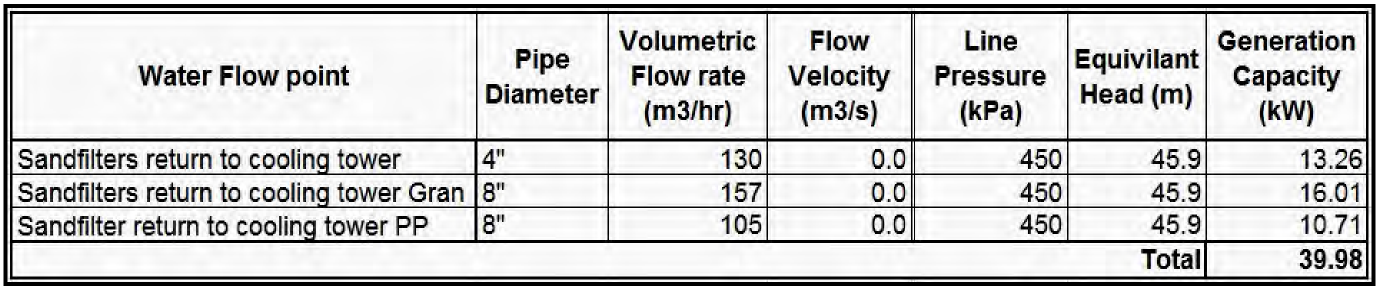
Water Flow point	Pipe Diameter	Volumetric Flow rate (m3/hr)	Flow Velocity (m3/s)	Line Pressure (kPa)	Equivilant Head (m)	Generation Capacity (kW)
Effluent	24"	5	0.0	1	0.1	0.00
CWR to cooling tower return HDPE	24"	2200	0.6	100	10.2	49.87
CWR to cooling tower return Gran	16" x 4	5000	1.4	100	10.2	113.33
CWR to cooling tower return PP	20"	2200	0.6	100	10.2	49.87
Sandfilters return to cooling tower	4"	130	0.0	100	10.2	2.95
Sandfilters return to cooling tower Gran	8"	157	0.0	100	10.2	3.56
Sandfilter return to cooling tower PP	8"	105	0.0	100	10.2	2.38
TPW return of extruder Line 0	8"	85	0.0	8	0.8	0.15
TPW return of extruder Line 3	10"	145	0.0	10	1.0	0.33
TPW return of extruder Line 4	10"	85	0.0	10	1.0	0.19
TPW return of extruder Line 5	10"	85	0.0	10	1.0	0.19
TPW return of extruder Line 7	10"	105	0.0	10	1.0	0.24
TPW return of extruder Line 8	10"	230	0.1	10	1.0	0.52
TPW return of extruder Line 9	10"	145	0.0	10	1.0	0.33
Site Municipal supply	8"	54	0.0	350	35.7	4.28
					Total	**228.19**

Table 4.10: Safripol hydro-energy total potential

The results in the table above indicate that the cooling tower systems provide the best opportunity (213 kW in total) to host hydro-power generators. The sand filter return lines add up to 8.89 kW in total. The extruder lines also add up to the least amount of power generated with the complete capacity calculated to be around 228 kW in total.

The formula to calculate the generation capacity utilizes the head or line pressure as an input to the formula. The position or location of the hydro-power generators can be moved on the sand filters to the supply side of the filter itself which will lead to an increase in capacity since the supply-line pressure to the filter is controlled at 450 kPa.

The table below shows the increase in generation capacity due to an increase in head or line pressure.



Water Flow point	Pipe Diameter	Volumetric Flow rate (m3/hr)	Flow Velocity (m3/s)	Line Pressure (kPa)	Equivilant Head (m)	Generation Capacity (kW)
Sandfilters return to cooling tower	4"	130	0.0	450	45.9	13.26
Sandfilters return to cooling tower Gran	8"	157	0.0	450	45.9	16.01
Sandfilter return to cooling tower PP	8"	105	0.0	450	45.9	10.71
					Total	**39.98**

Table 4.11: Sand-filter hydro-energy total potential at 450 kPa line pressure

The total generation capacity has increased from 8.89 kW to almost 40 kW. The position of the piped generators can be at any point on the filters without any major influence on the operation on the filter. This is, however, not possible for the rest of the applications as it would seriously influence the required flow to the operational plants.

4.5. Wind driven turbine generators

4.5.1. Required resources - summarized

Wind turbines differ from hydro-power generators only in the sense that they acquire kinetic energy to drive the turbines, which is extracted from gases and not liquids. The amounts of energy that are inherent in gases are much lower compared to liquids due to the density differences between the mediums.

It must therefore be kept in mind that the density of air or gas systems drops as temperatures increase. This will have a detrimental effect on the driving force from the medium and in some cases will lead to a system failure. When selecting an application the wind speed and temperature must be considered in order to size the wind turbines accordingly.

The swept area of turbine blades increases in relation with the generation capacity. This implies that the installation area and required space must be taken into consideration when designing wind-driven generation systems.

The turbines must be installed preferably at elevated points where the blade system is exposed to the maximum available winds. Micro-wind turbines may be installed at exhaust air ducts on existing structures, thus eliminating the need for high masts to host the turbine.

The generation capacity is capital-intensive due to the relatively small amount of kinetic energy that air possesses but this means of power generation is one of the least expensive to maintain.

4.5.2. Safripol potential

The manufacturing site is situated in an area that has been identified to have very low wind-power generation possibilities. The annual average mean wind speed for this area is 4 m/s, which is at the lower end of operation of any kind of large wind turbines. The cut in speeds of these large HAWT is rated to be 3.5 m/s and for the VAWT the speed is set at 1.5 m/s.

The physical location of the manufacturing site (Sasolburg) is set 1463 metres above sea level which further reduces the air density by 20.5% which is calculated to be 1.024 kg/m^3. It is therefore not really practicable to embark on expensive large-scale wind-turbine generators, without a proper analysis of the actual wind capacities and speeds for the specific location.

The manufacturing site does however consist of a number of high structures and buildings which may provide an ideal location for rooftop turbine installations should the wind analysis provide positive data. The facility also makes use of compressed air systems to transport product but these transport systems are fed back to the intake of the blowers, to form a closed loop.

On the HDPE facility hot air is used to dry the polymer powder at the fluid bed dryer system. The air contains small dust particles that are separated with the use of cyclones and a negative drive force in the form of exhaust fans or blowers. These blowers remove all air introduced into the dryers and the outlet of these blowers is open to the atmosphere.

There are six blowers in total, spread to be utilized on the three production trains K0, K1 and K0B. The six blowers are made up by three different models and sizes which are:

- Howden Donkin MRB 630 – 7m^3/s
- Buffalo Fan Co. H14 Series 890 – 5.2 m^3/s
- Buffalo Fan Co. H14 Series 1085 - 21.23 m^3/s

The temperature extracted from the dryer temperature is still relatively hot and the outlet temperature readings average around 55 °C.

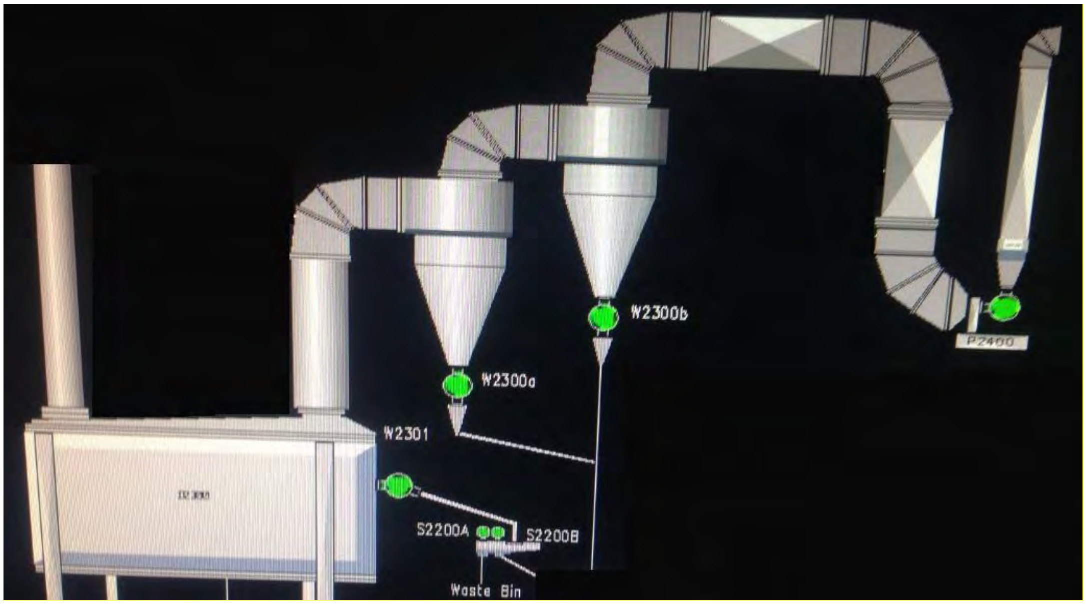
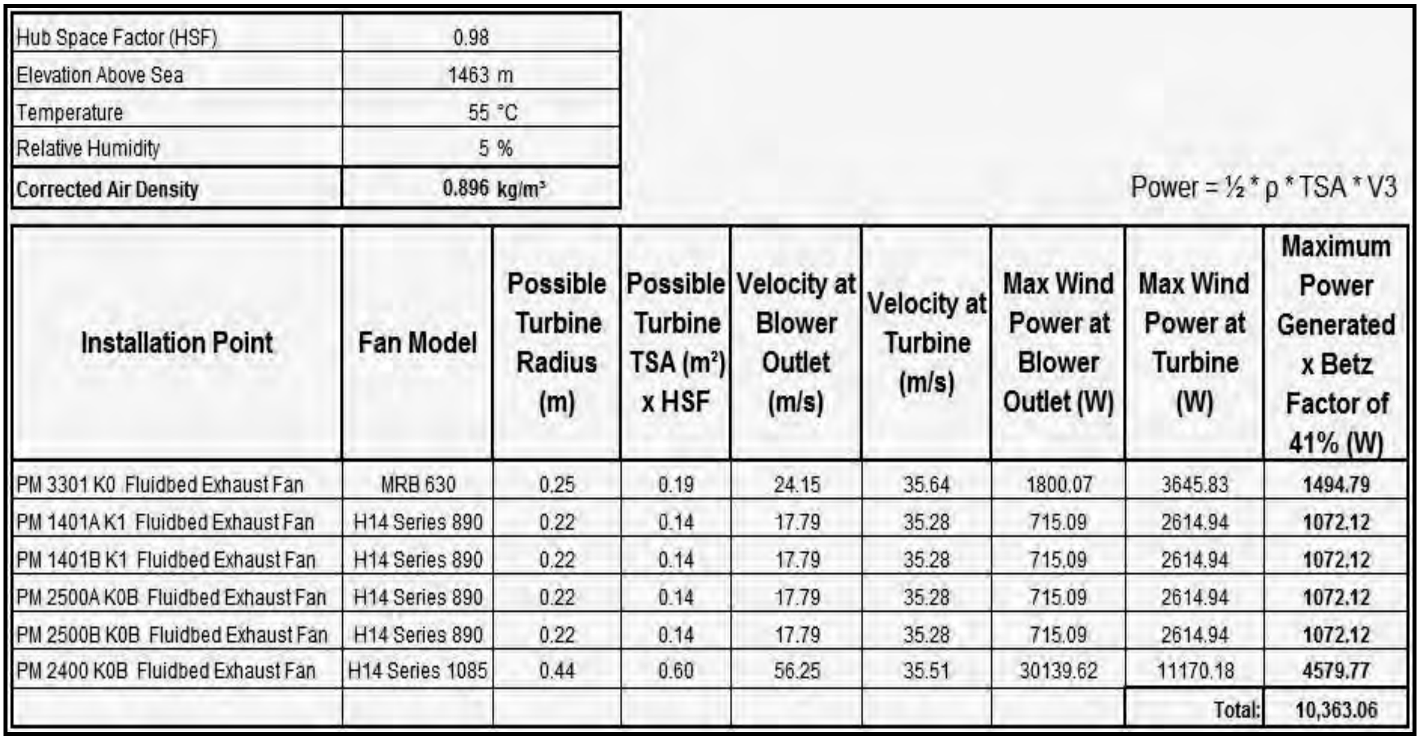


Figure 4.14: Fluid bed dryer exhaust system with the P2400 blower

When the elevation above sea level and the hot air temperature are taken into consideration, the actual air density at the outlet of these exhausts blowers, drops to a value of 0.896 kg/m^3. This might be a low value but, there is still some energy left in this waste stream.

The table below gives the total amounts of energy that were calculated at the discharge ends of these blowers. The calculations utilize the compensated density for the applications. The Total Swept Area (TSA) based on the possible turbine radiuses has been multiplied with a Hub Space Factor (HSF) in order to compensate for the area taken up by the turbine hub.



Hub Space Factor (HSF)	0.98
Elevation Above Sea	1463 m
Temperature	55 °C
Relative Humidity	5 %
Corrected Air Density	**0.896 kg/m³**

Power = ½ * ρ * TSA * V3

Installation Point	Fan Model	Possible Turbine Radius (m)	Possible Turbine TSA (m²) x HSF	Velocity at Blower Outlet (m/s)	Velocity at Turbine (m/s)	Max Wind Power at Blower Outlet (W)	Max Wind Power at Turbine (W)	Maximum Power Generated x Betz Factor of 41% (W)
PM 3301 K0 Fluidbed Exhaust Fan	MRB 630	0.25	0.19	24.15	35.64	1800.07	3645.83	**1494.79**
PM 1401A K1 Fluidbed Exhaust Fan	H14 Series 890	0.22	0.14	17.79	35.28	715.09	2614.94	**1072.12**
PM 1401B K1 Fluidbed Exhaust Fan	H14 Series 890	0.22	0.14	17.79	35.28	715.09	2614.94	**1072.12**
PM 2500A K0B Fluidbed Exhaust Fan	H14 Series 890	0.22	0.14	17.79	35.28	715.09	2614.94	**1072.12**
PM 2500B K0B Fluidbed Exhaust Fan	H14 Series 890	0.22	0.14	17.79	35.28	715.09	2614.94	**1072.12**
PM 2400 K0B Fluidbed Exhaust Fan	H14 Series 1085	0.44	0.60	56.25	35.51	30139.62	11170.18	**4579.77**
							Total:	**10,363.06**

Table 4.12: Exhaust fan outlet generation potential

On all the outlets (apart from PM2400) the wind turbines will need to be installed in conjunction with a venturi-type diffuser to enable an increase in wind velocity. This will double the generated power at the turbine blades compared to the blower outlets.

The possible turbine inlet radiuses of all options have been calculated to allow for wind velocities in the region of 35 m/s at the face of the turbine, which is in line with the maximum capacity of most wind-turbine technologies.

4.6. Financial results

The capital investment needed in order install the power generation system has been calculated according to the supported capacity and the results are presented in the rest of the chapter. Other options such as phased installations and the associated cost thereof have been investigated and presented as project execution alternatives.

The return on investment for all the different types of power generation opportunities which will aid future decision processes from a financial investment point of view is outlined below.

4.6.1. Historical data –Safripol consumption baseline

Safripol was established as a polymer-producing company in 1972 and in the years up to 1998 the company steadily expanded its operations to adapt to market-demand increases. In 1999 the company was bought over as part as an investment by the Dow Chemical company into the then Sentrachem group.

During the years following the takeover, Dow introduced a number of work processes which optimized the Safripol operations and aligned the business unit strictly to the manufacturing of polymers. Other functions such as civil workshops were closed and even the welding workshop was reduced to a virtual non-existence. Functions like these were outsourced and only the most important functions to support the operations were sustained. The work force in total was reduced from a head count of 550 to only 280 people.

This meant that the electricity consumption in total was also reduced accordingly for the years up to 2006, when Dow decided to disinvest and the company was bought over by a South African consortium. Once the support was cut from Dow, Safripol was forced to establish its own support systems and the work force count increased to around 300 people.

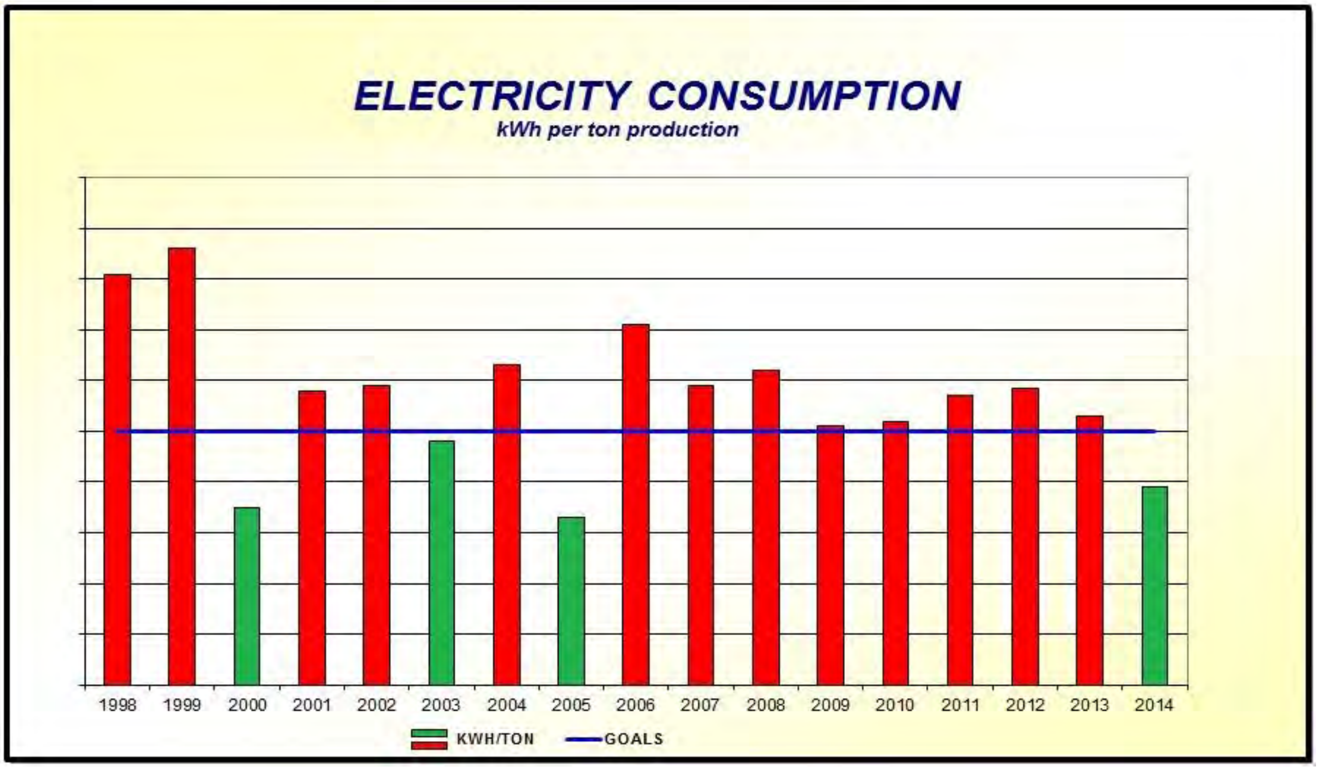


Figure 4.15: The electricity consumption for the years 1998 to 2014 (kWh per ton produced)

From the graph above it is clear that the consumption per ton of polymer produced followed the Dow/Safripol divestment. During the past seven years the consumption has stabilized just around the goal line set out for the company. Only on four occasions have the levels of consumption dipped under the goal line.

For the past sixteen years no major expansions have taken place at Safripol but future expansion plans will be greatly influenced by the electrical infrastructure and costs.

4.6.2. Data on Safripol electricity costs

Optimization of utilities has taken priority in the past years and the production processes have been improved accordingly. The electricity price from ESKOM, nonetheless, did not remain constant and this utility cost has almost quadrupled in the past seven years.

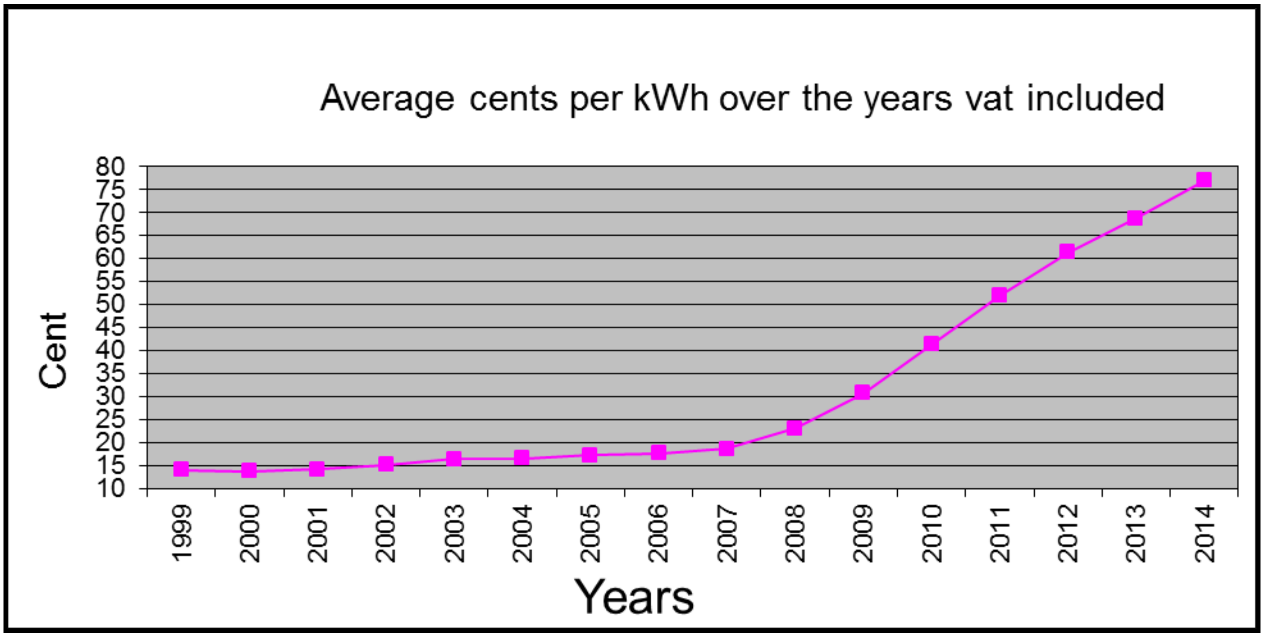


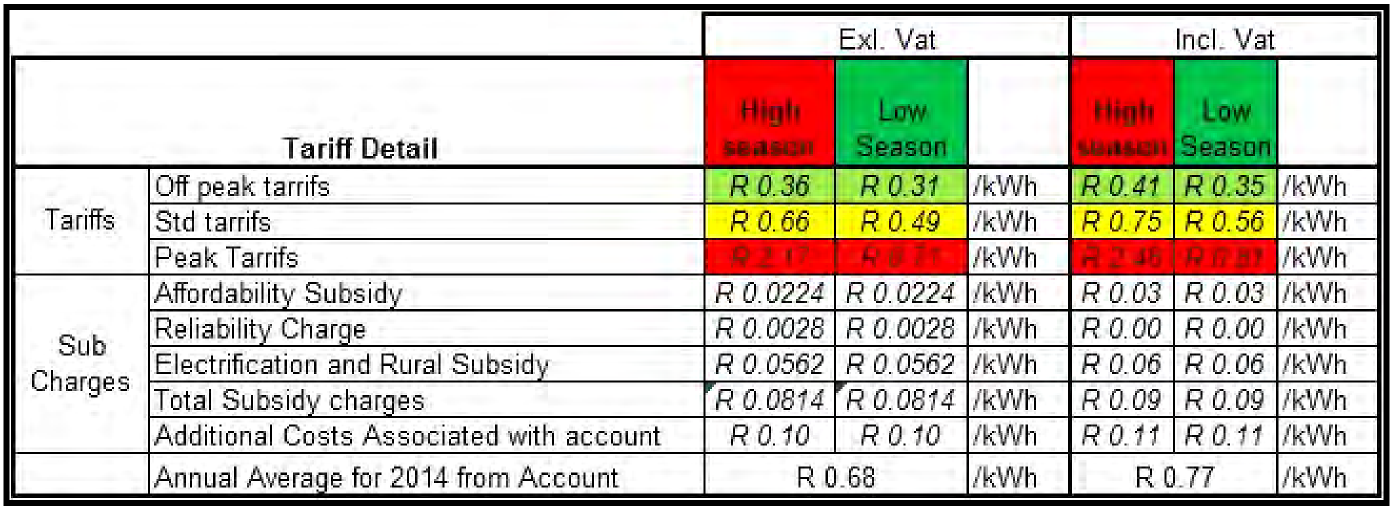
Figure 4.16: The electricity cost for the years 1999 to 2014 (cent/kWh)

The graph above represents the cost of electricity paid by Safripol. The figure is annualized to an average price which included summer lows and winter peak rates.

At the time of this study the facility is supplied power from ESKOM through the Mega-flex tariff system that allows large power users a flexible electricity charge rate. This provides the facility to control their electricity consumption during peak hours which is charged at higher rates. It also provides the opportunity to optimize the throughput of the facility to take advantage of the off-peak tariffs which are charged at the lowest rates.

The Mega-flex tariff system is also broken into two seasons, high-demand season and low-demand season, to help the national grid cope with high electricity demands during winter time.

The high demand season lasts for the 92 days of winter and the low demand season makes up the rest of the year which in total is 273 days. The table below is a breakdown of the electrical rates that Safripol is charged according to the Mega-flex rates.



Tariff Detail		Exl. Vat High season	Exl. Vat Low Season		Incl. Vat High season	Incl. Vat Low Season	
Tariffs	Off peak tarrifs	R 0.36	R 0.31	/kWh	R 0.41	R 0.35	/kWh
	Std tarrifs	R 0.66	R 0.49	/kWh	R 0.75	R 0.56	/kWh
	Peak Tarrifs	R 2.17	R 0.71	/kWh	R 2.46	R 0.81	/kWh
Sub Charges	Affordability Subsidy	R 0.0224	R 0.0224	/kWh	R 0.03	R 0.03	/kWh
	Reliability Charge	R 0.0028	R 0.0028	/kWh	R 0.00	R 0.00	/kWh
	Electrification and Rural Subsidy	R 0.0562	R 0.0562	/kWh	R 0.06	R 0.06	/kWh
	Total Subsidy charges	R 0.0814	R 0.0814	/kWh	R 0.09	R 0.09	/kWh
	Additional Costs Associated with account	R 0.10	R 0.10	/kWh	R 0.11	R 0.11	/kWh
	Annual Average for 2014 from Account	R 0.68		/kWh	R 0.77		/kWh

Table 4.13: Safripol electrical charge tariffs according to the ESKOM Mega-flex program

The Mega-flex tariff system is divided into different rates per peak demand hour over a twenty four hour day. During weekdays the application of Peak-tariffs is more profound than during the weekends where the whole of Sunday is charged at Off-peak tariffs. The picture below is an illustration of the peak demand hour application wheel chart.

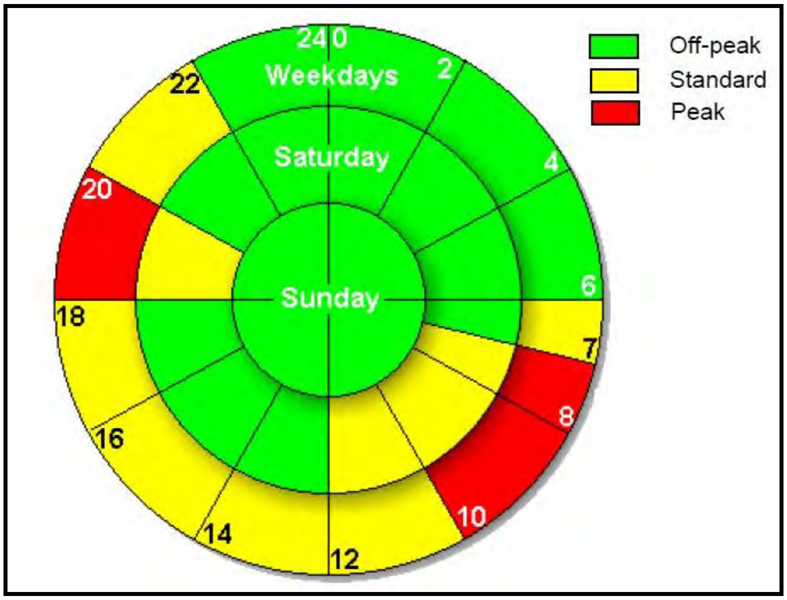


Figure 4.17: The Mega-flex hour tariff wheel (courtesy: ESKOM 2014)

The tariffs can thus be incorporated into an hourly table that will represent the charge rates according to the time of day.

Time of day	High season Mon	High season Tue	High season Wed	High season Thur	High season Fri	High season Sat	High season Sun	Low season Mon	Low season Tue	Low season Wed	Low season Thur	Low season Fri	Low season Sat	Low season Sun
00h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
01h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
02h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
03h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
04h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
05h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
06h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
07h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
08h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
09h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
10h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
11h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
12h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
13h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
14h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
15h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
16h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
17h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
18h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.41	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.35	R 0.35
19h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
20h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
21h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
22h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
23h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
Day Hourly Average	R 0.91	R 0.91	R 0.91	R 0.91	R 0.91	R 0.51	R 0.41	R 0.52	R 0.52	R 0.52	R 0.52	R 0.52	R 0.41	R 0.35

Figure 4.18: Electricity cost per hour according to Mega-flex tariffs (R/kWh)

Safripol's annual average for electricity costs is calculated to be R0.77 per kWh for the year 2014. The electrical costs from ESKOM will continue to increase as per agreed NERSA rates at minimum of 8% per year, for the following five years.

At the time of this study NERSA had approved additional increases in electricity tariffs due to the Regulatory Clearing Account (RCA) balance for ESKOM. This will lead to added increases over and above the 8% approved by NERSA. The additional increase for the 2015/16 financial year is estimated to be between 3.5% and 5.5% (over and above the 8%), which will continue for the following five years.

The additional increase in electricity will have a big impact on the cost of this utility even if the minimum amount of 11.5% is granted by NERSA in 2015. This calculates to an electricity cost of R1.33 per kWh in 2019 rand value.

4.6.3. Tax incentives provided by SARS

In 2013 the South African government decided to introduce carbon tax and related incentive programmes to assist companies to reduce their Green House Gas (GHG) emissions. The National Treasury published the Carbon Tax Policy Paper in May 2013 which stipulates that companies will be charged taxes related to GHG emissions generated from fuel combustion, gasification and non-energy industrial processes. This policy paper will apply to all sectors with the exception of agriculture, forestry and land-use.

The carbon tax policy will be introduced in two phases which will range from 2016 up to 2020, and the second part from 2020 up to 2025. In phase one the tax applied will be R120 per ton CO_2 equivalent which will increase at 10% per year up to 2019. Carbon offsets applicable to power generated from renewable resources will provide the companies an opportunity to reduce their carbon taxes accordingly.

The carbon intensity of electricity produced in South Africa is calculated to be 0.87kg/kWh (SAGEN, 2013). This value can be used to calculate the total carbon emissions avoided, which will relate a direct carbon tax reduction.

According to the Income Tax Act 58 of 1962, any business can depreciate assists procured over a five-year period. This allows for a tax reduction based on the assets procured, at 20% per year, for the first five years after procurement. Section 12B relates to renewable energy, and allows for an accelerated depreciation of assets procured in the use to generate renewable energy.

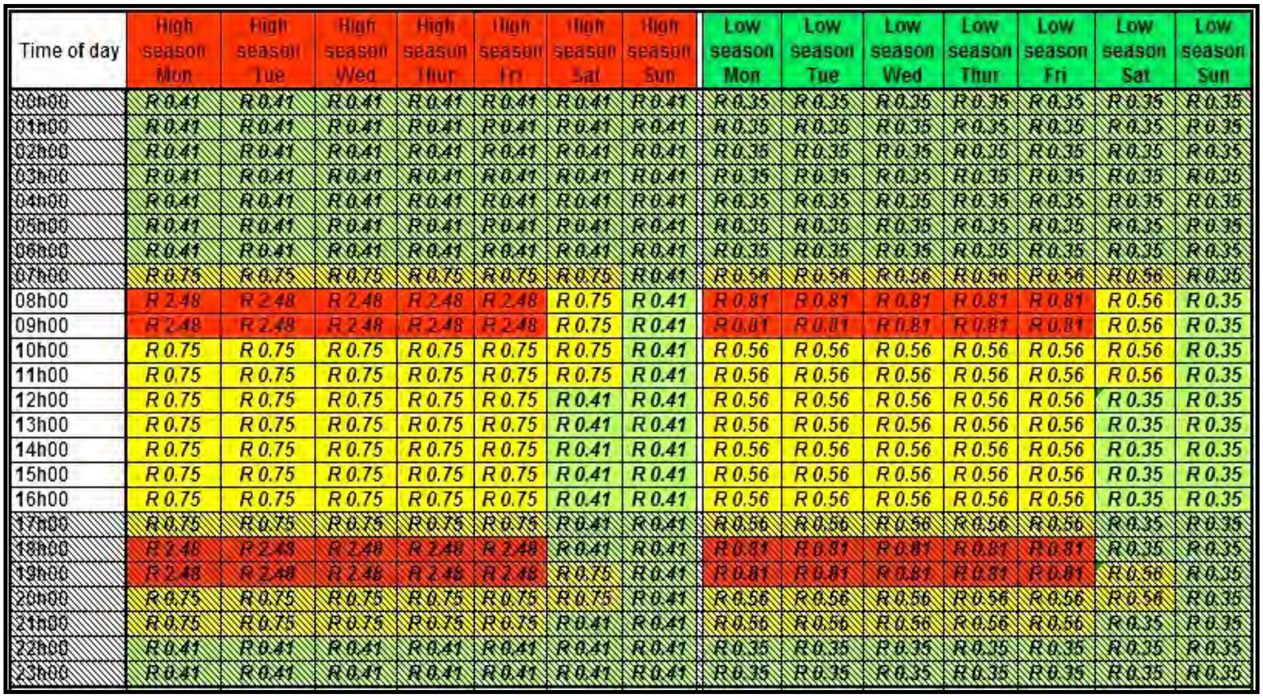
The depreciation allowance is 50% of the cost for the equipment in the first year it was procured, then 30% in the second year and the remainder of 20% in the third and last year after procurement. The allowance provides an accelerated return on investment due to additional tax benefits during the first three years of a project related to renewable energy.

4.7. PV Solar generation - Financials

Chapter two presented the historical financial data for PV solar power generation. The cost for PV panels has steadily decreased during the past twenty years at a rate of 10.8% per year. This decrease in Solar PV panel prices was due to the rapid growth in demand for this means of power generation, which in turn initiated mass production of PV panels from all over the world.

The cost of PV solar panels is expected to continue to decline, although at a slower rate. This provides a reason to assume that the installed cost of Solar PV will be kept constant at R20/W_p for the years to come.

Solar PV generation will only be possible from 8h00 to 16h00 which coincides with the peak tariffs on the Mega-flex; this is an added financial advantage.



Time of day	High season Mon	High season Tue	High season Wed	High season Thur	High season Fri	High season Sat	High season Sun	Low season Mon	Low season Tue	Low season Wed	Low season Thur	Low season Fri	Low season Sat	Low season Sun
00h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
01h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
02h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
03h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
04h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
05h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
06h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
07h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
08h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
09h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
10h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
11h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
12h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
13h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
14h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
15h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
16h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
17h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
18h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.41	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.35	R 0.35
19h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
20h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
21h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
22h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
23h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35

Figure 4.19: Mega-flex tariffs time-frame applicable to Solar PV generation (R/kWh)

The mean average of electricity during this time frame averages out at R0.86 per kWh for 2014.The escalation in electricity costs on an annual basis has been set at 11.5% per year.

The financials in the tables below will be done covering two installation approaches. One approach will look at an all-inclusive investment to install a 600 kW_p PV solar power plant as a once-off capital investment. The other approach will include phased installations which will stagger the capital investments over a period of ten years until the full capacity of 4,5 MW is reached.

Savings on carbon taxes are included in the calculation as a benefit from 2016 (Year 2) and this value will escalate according to the carbon tax inflation set at 10% per year. The maintenance cost is calculated at 0.84% of the installed cost in Year 0. The maintenance cost is linked to increase according to the CPI (6.6%) for the years to come.

This form of power generation lends itself to a phased installation as the complete PV solar-generation system is modular in design. This advantage allows the end user to invest a small portion of capital in this means of power generation. The return on investment can then fund future expansions since the input energy to the system (light from the sun) is free of charge.

The re-investment capital is sourced from the total income from the previous year. This value represents the saving in electricity costs due to the solar installation which provides electrical energy, for a period of eight hours (8h00 to 16h00) per day for 365 days a year. There is no carbon tax savings for Year 0 and Year 1 but, from Year 2 onwards this saving is included in the available capital for re-investment.

The re-investment calculations delivered a result of having a total system installed with a capacity of 4.5 MW at the end of ten years. The total income from avoided electricity charges added up to be R34 million per year which is quite substantial when considering that the initial investment capital was only R12 million.

Table 4.14 represents all the data required to be entered into the financial calculation sheets used at the Safripol facility. The calculation is based on the 600 kW_p size plant but, due to a fixed installation cost (R20,000/kWhp) the rest of the calculations all result in the equivalent values.

PV Solar Power Installation - Financial Input											
Installation Point - Warehouse F	**Year 0 - 2014**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Installed Cost (ZAR/kW)	R 20,000.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Maximum Capacity (kW)	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00
Total Capital investment - Installed (ZAR)	R 12,000,000	0	0	0	0	0	0	0	0	0	0
Maintenance Factor	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%
Total Annualized Maintenance cost	R 100,800	R 100,800.00	R 100,800.00	R 100,800.00	R 100,800.00	R 100,800.00	R 100,800.00	R 100,800.00	R 100,800.00	R 100,800.00	R 100,800.00
Inflation Rate (CPI)	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%
Cost of Electricity Annual Average (ZAR/kWh)	R 0.86	R 0.96	R 1.07	R 1.19	R 1.33	R 1.48	R 1.65	R 1.84	R 2.05	R 2.29	R 2.55
Total Electricity Generated Annual (kWh)	1,752,000	1,752,000	1,752,000	1,752,000	1,752,000	1,752,000	1,752,000	1,752,000	1,752,000	1,752,000	1,752,000
Income from Electrical Cost Avoidance	R 1,506,720	R 1,679,993	R 1,873,192	R 2,088,609	R 2,328,799	R 2,596,611	R 2,895,221	R 3,228,172	R 3,599,411	R 4,013,344	R 4,474,878
Annual Increase of Electricity cost	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%
Carbon CO_2 tax (ZAR/ton)	R 0	R 0	R 120	R 132	R 145	R 160	R 176	R 193	R 213	R 234	R 257
Total Saved Carbon tax (ZAR)	R 0	R 0	R 182,909	R 201,200	R 221,320	R 243,452	R 267,797	R 294,576	R 324,034	R 356,438	R 392,081
Carbon Intensity for Electricity Generation in RSA (kg/kWh)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Total Carbon Emmissions avoided (ton)	1,524.24	1,524.24	1,524.24	1,524.24	1,524.24	1,524.24	1,524.24	1,524.24	1,524.24	1,524.24	1,524.24
Carbon Tax Annual increase	0.0%	0.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Re-investment Program	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Installed Cost (ZAR/kW)	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00	R 20,000.00
Potential Capacity (kW)	0.00	75.34	88.87	125.15	163.61	217.35	293.79	404.77	569.55	820.13	1,211.09
Total Capital Re-investment (ZAR)	R 0	R 1,506,720.00	R 1,777,476.25	R 2,503,089.84	R 3,272,297.62	R 4,347,082.62	R 5,875,728.07	R 8,095,408.66	R 11,391,038.78	R 16,402,580.75	R 24,221,786.95
Maintenance Factor	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%	0.84%
Total Annualized Maintenance cost	R 0	R 113,456	R 115,731	R 121,826	R 128,287	R 137,315	R 150,156	R 168,801	R 196,485	R 238,582	R 304,263
Infaltion Rate (CPI)	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%
Cost of Electricity Annual Average (ZAR/kWh)	R 0.86	R 0.96	R 1.07	R 1.19	R 1.33	R 1.48	R 1.65	R 1.84	R 2.05	R 2.29	R 2.55
Total Electricity Generated Annual (kWh)	0	1,971,981	2,231,493	2,596,944	3,074,699	3,709,373	4,567,230	5,749,159	7,412,251	9,807,028	13,343,409
Income from Electrical Cost Avoidance	R 0	R 1,890,933	R 2,385,853	R 3,095,891	R 4,086,962	R 5,497,602	R 7,547,454	R 10,593,192	R 15,228,162	R 22,465,167	R 34,081,124
Annual Increase of Electricity cost	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%
Total Saved Carbon tax (ZAR)	R 0	R 0	R 232,968	R 298,233	R 388,408	R 515,441	R 698,110	R 966,648	R 1,370,903	R 1,995,201	R 2,986,130
Carbon CO_2 tax (ZAR/ton)	R 0	R 0	R 120	R 132	R 145	R 160	R 176	R 193	R 213	R 234	R 257
Carbon Intensity for Electricity Generation in RSA (kg/kWh)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Total Caron Emmissions avoided (ton)	1,524.24	1,715.62	1,941.40	2,259.34	2,674.99	3,227.15	3,973.49	5,001.77	6,448.66	8,532.11	11,608.77
Total System Capacity per Hour (kWp)	***600.00***	***675.34***	***764.21***	***889.36***	***1,052.98***	***1,270.33***	***1,564.12***	***1,968.89***	***2,538.44***	***3,358.57***	***4,569.66***

Table 4.14: PV Solar financial data input sheet and re-investment calculation

The simple payback is calculated to be five years and five months, and the discounted payback calculated to be eight and a half years.

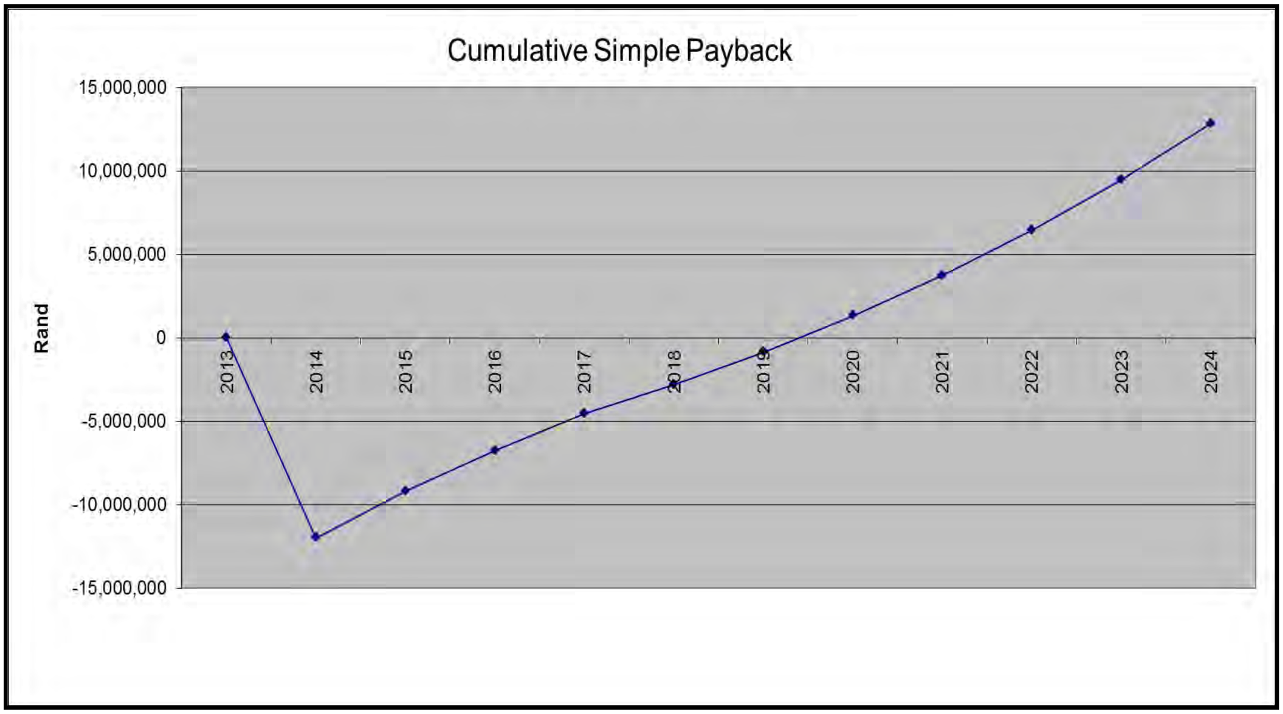


Figure 4.20: Simple payback for Solar PV generation

The WACC is set at 12.12% according to the equity and cost of debt formula discussed in chapter 3. The depreciation of the total investment is calculated over a period of three years (50%, 30% and 20% respectively).

From the calculations in Table 4.15 the following financial results can be presented:

- Profitability Index = 1.14
- NPV of Cash Flow = Rm 1,622
- IRR = 15.3%

Net Cash Flow	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
PV Solar Power Installation - Financial Input	Y0	1	2	3	4	5	6	7	8	9	10
Net Capital Costs											
PV Solar Power Financial Calculation	-R 12,000,000.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Total Capital	**-R 12,000,000.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**
Operating and Maintenance Costs											
Cost 1		-R 100,800.00	-R 100,800.00	-R 100,800.00	-R 100,800.00	-R 100,800.00	-R 100,800.00	-R 100,800.00	-R 100,800.00	-R 100,800.00	-R 100,800.00
Cost 2		R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Escalation of Costs		-R 6,652.80	-R 13,744.68	-R 21,304.63	-R 29,363.54	-R 37,954.33	-R 47,112.12	-R 56,874.32	-R 67,280.82	-R 78,374.16	-R 90,199.65
Total Costs	**R 0.00**	**-R 107,452.80**	**-R 114,544.68**	**-R 122,104.63**	**-R 130,163.54**	**-R 138,754.33**	**-R 147,912.12**	**-R 157,674.32**	**-R 168,080.82**	**-R 179,174.16**	**-R 190,999.65**
Revenue and Operating Benefits											
Reduced Power consuption form Eskom		R 1,679,992.80	R 1,873,191.97	R 2,088,609.05	R 2,328,799.09	R 2,596,610.98	R 2,895,221.25	R 3,228,171.69	R 3,599,411.44	R 4,013,343.75	R 4,474,878.28
Tax Incentive on Power Saving		R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Reduced Carbon Tax		R 0.00	R 182,908.80	R 201,199.68	R 221,319.65	R 243,451.61	R 267,796.77	R 294,576.45	R 324,034.10	R 356,437.51	R 392,081.26
Escalation of Benefits		R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Total Benefits and Revenue	**R 0.00**	**R 1,679,992.80**	**R 2,056,100.77**	**R 2,289,808.73**	**R 2,550,118.74**	**R 2,840,062.60**	**R 3,163,018.02**	**R 3,522,748.14**	**R 3,923,445.53**	**R 4,369,781.26**	**R 4,866,959.54**
Cash Flow Before Taxes	**-R 12,000,000.00**	**R 1,572,540.00**	**R 1,941,556.09**	**R 2,167,704.09**	**R 2,419,955.20**	**R 2,701,308.26**	**R 3,015,105.90**	**R 3,365,073.82**	**R 3,755,364.71**	**R 4,190,607.10**	**R 4,675,959.89**
Income Tax Calculation											
Depreciation Expense		-R 6,000,000.00	-R 3,600,000.00	-R 2,400,000.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Operating Cost		-R 107,452.80	-R 114,544.68	-R 122,104.63	-R 130,163.54	-R 138,754.33	-R 147,912.12	-R 157,674.32	-R 168,080.82	-R 179,174.16	-R 190,999.65
Operating Benefits		R 1,679,992.80	R 2,056,100.77	R 2,289,808.73	R 2,550,118.74	R 2,840,062.60	R 3,163,018.02	R 3,522,748.14	R 3,923,445.53	R 4,369,781.26	R 4,866,959.54
Net Income Taxes	**R 0.00**	**R 1,239,688.80**	**R 464,364.30**	**R 65,042.85**	**-R 677,587.46**	**-R 756,366.31**	**-R 844,229.65**	**-R 942,220.67**	**-R 1,051,502.12**	**-R 1,173,369.99**	**-R 1,309,268.77**
Cash Flow After Taxes	**-R 12,000,000.00**	**R 2,812,228.80**	**R 2,405,920.38**	**R 2,232,746.95**	**R 1,742,367.74**	**R 1,944,941.95**	**R 2,170,876.25**	**R 2,422,853.15**	**R 2,703,862.59**	**R 3,017,237.11**	**R 3,366,691.12**
Discounted Cash Flow (After Tax)	**-R 12,000,000.00**	**R 2,508,320.67**	**R 1,914,018.19**	**R 1,584,297.44**	**R 1,102,730.64**	**R 1,097,914.88**	**R 1,093,023.50**	**R 1,088,062.72**	**R 1,083,038.41**	**R 1,077,956.13**	**R 1,072,821.14**
Business Case Results:				**Assumptions:**							
NPV of Cash Flow	**R 1,622,183.71**			Cost Escalation Factor		6.60%					
IRR	**15.3%**			Benefit Escalation Factor		0.00%	Calculated at NERSA increases				
Profitability Index	**1.14**			Income Tax Rate		28.00%					
Simple Payback	5 Years 5 Months			WACC		12.12%					
Discounted Payback	8 Years 6 Months										

Table 4.15: PV Solar financial calculation results

4.8. Electricity generation from hydrocarbon waste - financials

The financial model for hydrocarbon-based power generation has been completed in two models. The first model will be based on generating power from hydrocarbon waste in the form of recovered flare gas. The total capacity from this type of generation averaged out to 2,432.59 kWh.

The second model will use solid and liquid hydrocarbon waste as fuel in order to generate steam through an incineration process. The process has a total capacity of 2,125 kWh and also provides additional steam for use in processes.

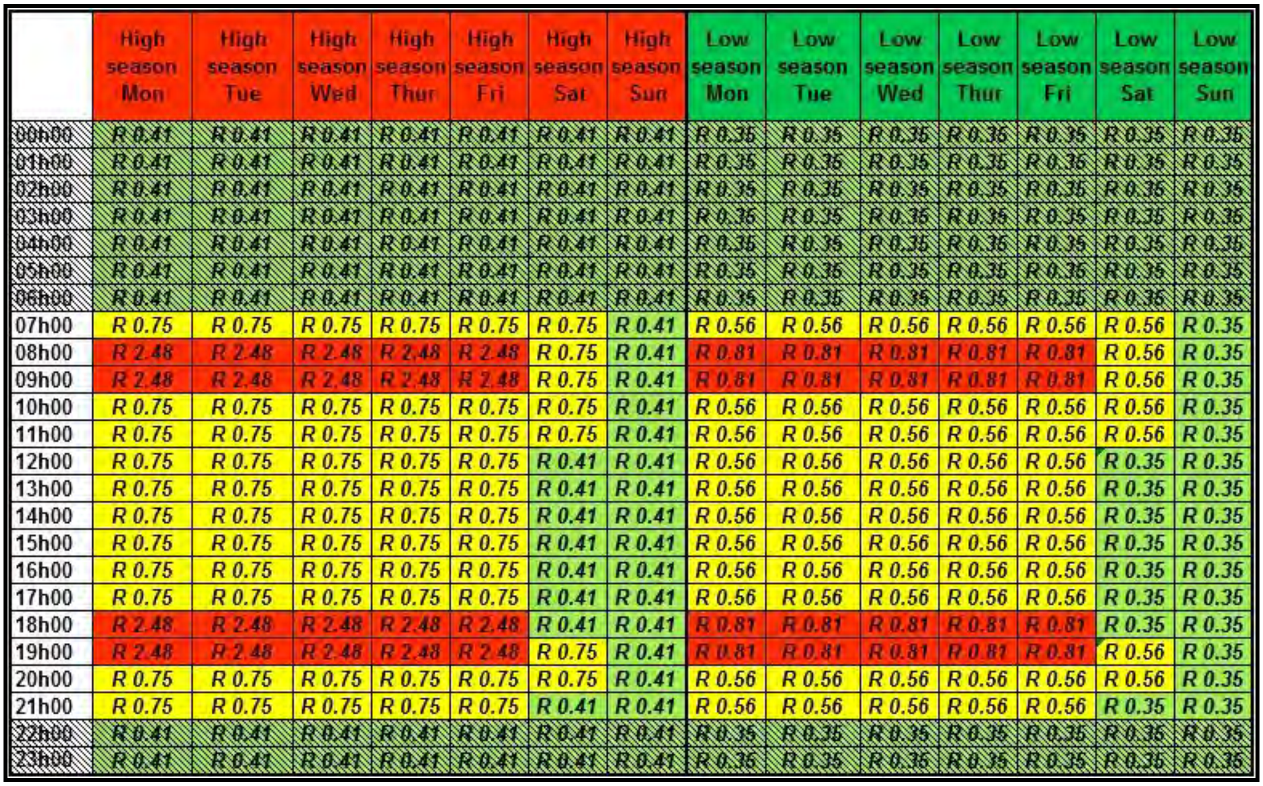
Variable steam costs, waste disposal costs and recycling income have been tabled in the table below. The data will be used in both financial models in order to capture the gains provided with this means of power generation.

Year	Steam Variable Cost (ZAR/Mton)	Steam Price Increase	Plastic Price for Recycling (R/kg)	% Waste Disposed	% Waste Recycled	Waste Disposal Cost (R/Mt)	Disposal Cost Increase	Waste Recycle Income (R/MT)
2008	R 43.26	6.84%	R 4.24	26.00%	74.00%	R 1,501.00	-	-
2009	R 46.22	8.44%	R 3.41	12.00%	88.00%	R 1,904.00	26.85%	-
2010	R 50.12	22.19%	R 3.55	10.30%	89.70%	R 2,197.00	15.39%	-
2011	R 61.24	14.26%	R 3.85	19.10%	80.90%	R 1,455.00	-33.77%	-
2012	R 69.97	1.36%	R 3.81	24.30%	75.70%	R 1,036.00	-28.80%	R 2,448.00
2013	R 70.92	19.95%	R 4.39	16.10%	83.90%	R 1,739.00	67.86%	R 3,008.00
2014	R 85.07	0.00%	R 4.88	13.80%	86.20%	R 3,169.00	82.23%	R 3,032.00
	Average:	**12.17%**	**R 4.02**	**17.97%**	**82.03%**	**R 1,857.29**	**21.63%**	**R 2,829.33**

Table 4.16: Safripol waste stream disposal costs and recycling income

4.8.1. Generation using recovered flare gas - financials

Utilizing recovered flare gas, rich in hydrocarbons, will benefit an internal combustion generation unit. The fuel gas can also be compressed and stored in a liquid format, for use during peak tariff periods only. The figure below provides the Mega-flex tariff time-frame which will provide maximum return on the fuel utilized. The average annual tariff used is calculated between 7h00 and 21h00, a period of 14 hours per day. The average tariff is calculated to be R0.87/kWh.



	High season Mon	High season Tue	High season Wed	High season Thur	High season Fri	High season Sat	High season Sun	Low season Mon	Low season Tue	Low season Wed	Low season Thur	Low season Fri	Low season Sat	Low season Sun
00h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
01h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
02h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
03h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
04h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
05h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
06h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
07h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
08h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
09h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
10h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
11h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
12h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
13h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
14h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
15h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
16h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
17h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
18h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.41	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.35	R 0.35
19h00	R 2.48	R 2.48	R 2.48	R 2.48	R 2.48	R 0.75	R 0.41	R 0.81	R 0.81	R 0.81	R 0.81	R 0.81	R 0.56	R 0.35
20h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35
21h00	R 0.75	R 0.75	R 0.75	R 0.75	R 0.75	R 0.41	R 0.41	R 0.56	R 0.56	R 0.56	R 0.56	R 0.56	R 0.35	R 0.35
22h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35
23h00	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.41	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35	R 0.35

Figure 4.21: Mega-flex tariffs time frame applicable to FGR internal combustion generation (R/kWh)

The generation unit selected for this financial model is a Caterpillar G3616 LE (System 4, Table 2.9) which delivers 3 MWh and with an efficiency rated at 73%. The installed cost is calculated to total R17,807/kW, which totals R53,4 million according to the rated generation capacity. The emission taxes and financial implications have been left out of the calculation due to the fact that the gas would have been combusted at the flare system. There is thus no saving or penalty associated in this regard.

The site has one high-pressure storage tank, V22005 (capacity: 772m^3), at the propylene storage facility, which is not currently in use by the production facility. This provides the ideal fuel storage solution which eliminates the capital needed to build storage infrastructure.

The production facilities are not fitted with flare gas recovery compressors which necessitate the need to install two such compressor units at the HDPE and PP production plants respectively. The cost for such a liquid ring compressor unit is set at R6.7 million each.

The use of hot exhaust gas enables an added advantage in the form of low-pressure steam generation capabilities. The steam calculations are based on the specific enthalpy steam at 3 bar gauge and 200°C, which is 2.725 MJ/kg. The variable cost of steam is taken from the results in table 4.16, which is set R85.07 per metric ton, escalated at 6.6% p.a.

Maintenance costs for the power generation unit are calculated at a cost factor of R43.10 per operational hour. This totals to a value of R220, 241 per year for the 14 hours per day as discussed above.

The liquid ring compressor maintenance and operational cost is set at R2 million for the two units per year (data sourced from Envirocomb Ltd.). As seen from the flare gas trends in Figure 4.9, the compressor units will not run continuously, but come into operation during plant upsets. This will still add to an electricity consumption value to run the motors which drives the compressor units. All operational and maintenance costs are escalated at 6.6% p.a.

Internal Combustion Process Peak Time Running (7h00 to 21h00)											
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Installed Cost (ZAR/kW)	R 17,807.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Maximum Capacity (kW)	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00
Total Capital investment - Installed (ZAR)	R 66,821,000	0	0	0	0	0	0	0	0	0	0
Total Cost for FGR Compression Unit (ZAR)	R 13,400,000										
Total Electricity Generated Annual (kWh)	15,330,000	15,330,000	15,330,000	15,330,000	15,330,000	15,330,000	15,330,000	15,330,000	15,330,000	15,330,000	15,330,000
Genset Maintenance Factor (ZAR/oph)	R 43.10	R 45.94	R 48.98	R 52.21	R 55.66	R 59.33	R 63.24	R 67.42	R 71.87	R 76.61	R 81.67
Total Annualized Maintenance cost for Genset (ZAR)	R 220,241	R 234,777	R 250,272	R 266,790	R 284,398	R 303,169	R 323,178	R 344,507	R 367,245	R 391,483	R 417,321
FGR Operational and Maintenance Cost (ZAR)	R 2,000,000	R 2,132,000	R 2,272,712	R 2,422,711	R 2,582,610	R 2,753,062	R 2,934,764	R 3,128,459	R 3,334,937	R 3,555,043	R 3,789,676
Inflation Rate (CPI)	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%
Heat Energy Recovered for Steam Generation (MJ/h)	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00
Specific enthalpy steam @ 3barg and 200°C (MJ/kg)	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725
Cost of Steam (ZAR/MT)	R 85.1	R 90.7	R 96.7	R 103.1	R 109.9	R 117.1	R 124.8	R 133.1	R 141.9	R 151.2	R 161.2
Annual Steam Generation Potential @ 85% Efficiency (ton)	17692.8	17692.8	17692.8	17692.8	17692.8	17692.8	17692.8	17692.8	17692.8	17692.8	17692.8
Steam Generation Saving	R 1,505,125.6	R 1,604,463.8	R 1,710,358.5	R 1,823,242.1	R 1,943,576.1	R 2,071,852.1	R 2,208,594.4	R 2,354,361.6	R 2,509,749.5	R 2,675,392.9	R 2,851,968.9
Cost of Electricity Annual Average (ZAR/kWh)	R 0.87	R 0.97	R 1.08	R 1.21	R 1.34	R 1.50	R 1.67	R 1.86	R 2.08	R 2.32	R 2.58
Income from Electrical Cost Avoidance	R 13,337,100	R 14,870,867	R 16,581,016	R 18,487,833	R 20,613,934	R 22,984,536	R 25,627,758	R 28,574,950	R 31,861,069	R 35,525,092	R 39,610,478
Annual Increase of Electricity Cost	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%

Table 4.17: Flare-gas recovery generation – inputs into financial model

The simple payback of the investment is calculated to be four years and three months and the discounted payback calculated to a period of just over six years. The figure below provides the simple payback period graph.

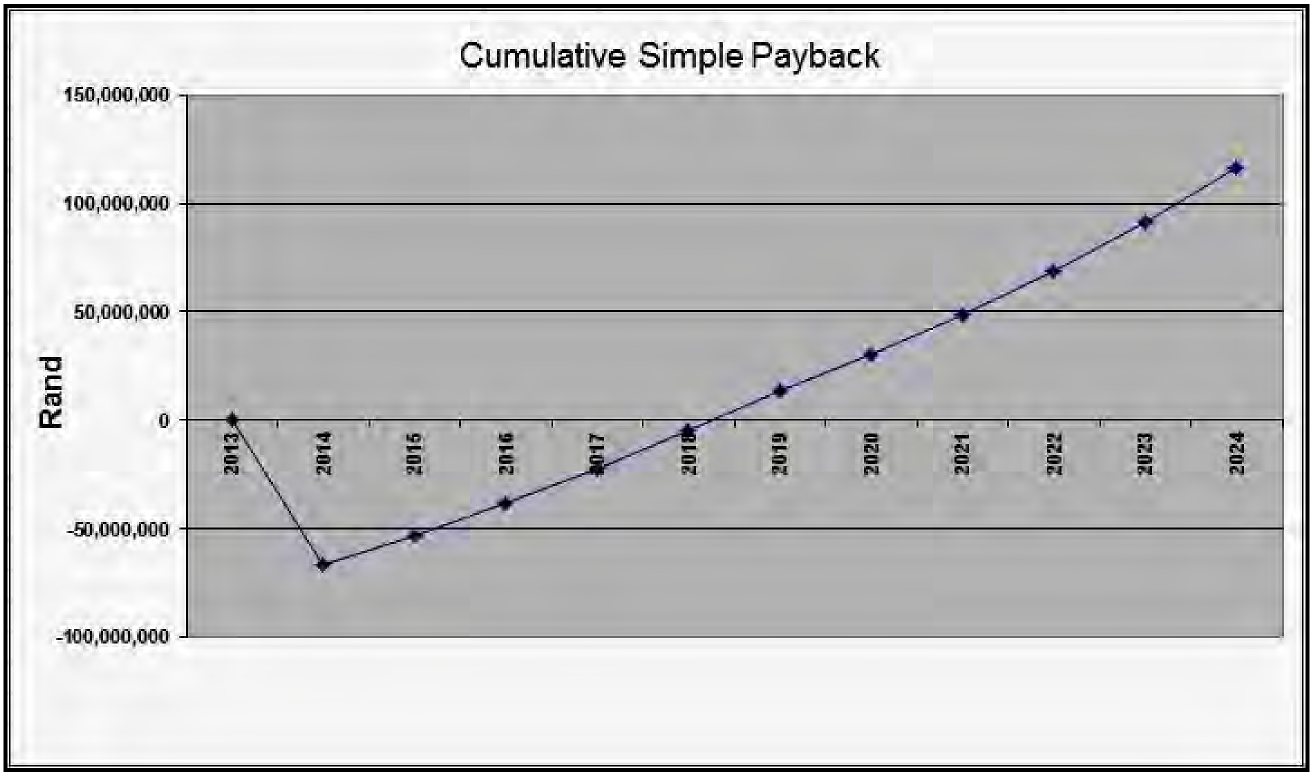
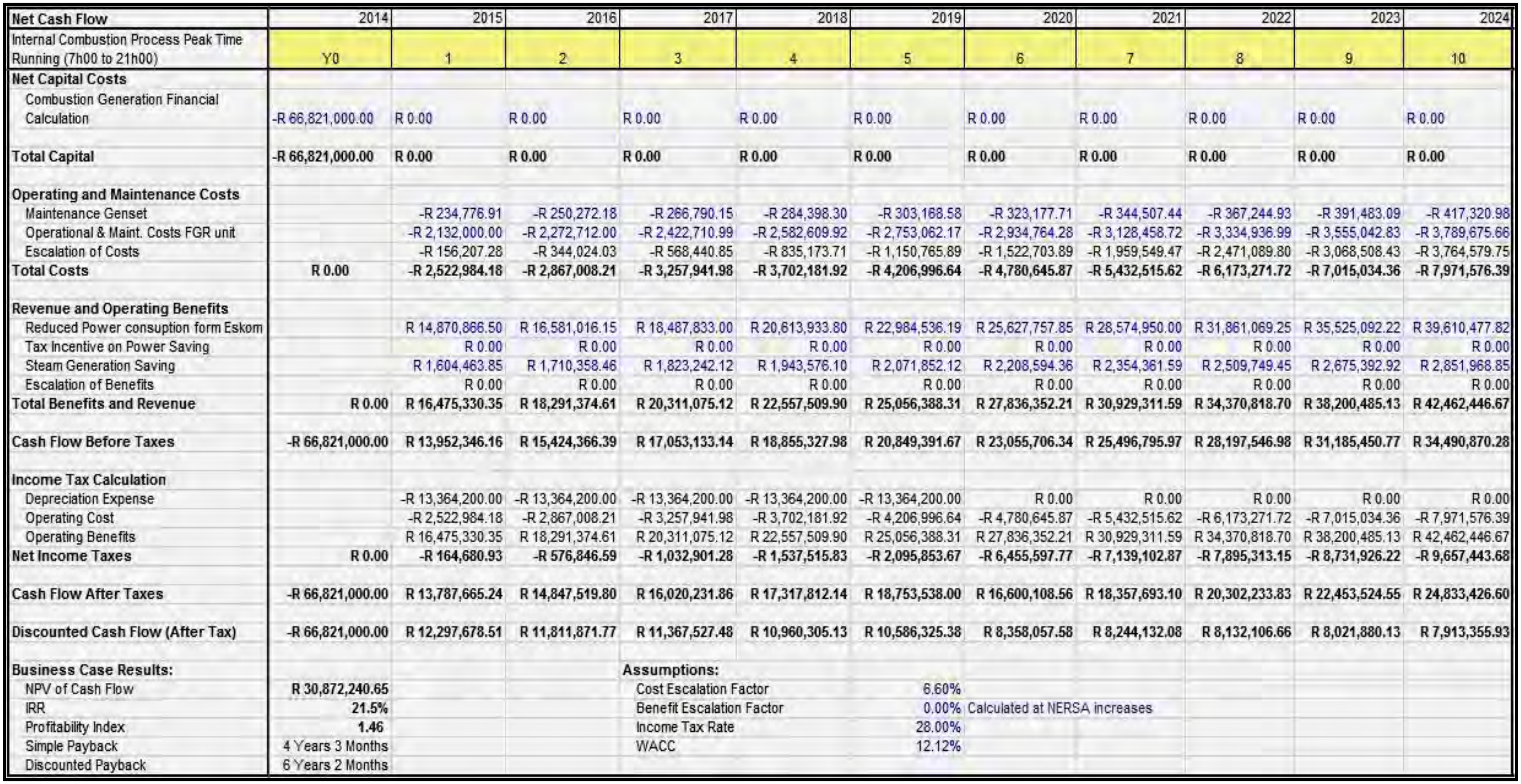


Figure 4.22: Simple payback for FGR generation

Power generation from hydrocarbon waste is not considered to be a renewable source of power generation. This entails that the depreciation is calculated over five years, which is the standard for capital investments.

From the calculations in Table 4.18 the following financial results can be presented:

- Profitability Index = 1.46
- NPV of Cash Flow = Rm 30,872
- IRR = 21.5%



Net Cash Flow	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Internal Combustion Process Peak Time Running (7h00 to 21h00)	Y0	1	2	3	4	5	6	7	8	9	10
Net Capital Costs											
Combustion Generation Financial Calculation	-R 66,821,000.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Total Capital	**-R 66,821,000.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**
Operating and Maintenance Costs											
Maintenance Genset		-R 234,776.91	-R 250,272.18	-R 266,790.15	-R 284,398.30	-R 303,168.58	-R 323,177.71	-R 344,507.44	-R 367,244.93	-R 391,483.09	-R 417,320.98
Operational & Maint. Costs FGR unit		-R 2,132,000.00	-R 2,272,712.00	-R 2,422,710.99	-R 2,582,609.92	-R 2,753,062.17	-R 2,934,764.28	-R 3,128,458.72	-R 3,334,936.99	-R 3,555,042.83	-R 3,789,675.66
Escalation of Costs		-R 156,207.28	-R 344,024.03	-R 568,440.85	-R 835,173.71	-R 1,150,765.89	-R 1,522,703.89	-R 1,959,549.47	-R 2,471,089.80	-R 3,068,508.43	-R 3,764,579.75
Total Costs	**R 0.00**	**-R 2,522,984.18**	**-R 2,867,008.21**	**-R 3,257,941.98**	**-R 3,702,181.92**	**-R 4,206,996.64**	**-R 4,780,645.87**	**-R 5,432,515.62**	**-R 6,173,271.72**	**-R 7,015,034.36**	**-R 7,971,576.39**
Revenue and Operating Benefits											
Reduced Power consuption form Eskom		R 14,870,866.50	R 16,581,016.15	R 18,487,833.00	R 20,613,933.80	R 22,984,536.19	R 25,627,757.85	R 28,574,950.00	R 31,861,069.25	R 35,525,092.22	R 39,610,477.82
Tax Incentive on Power Saving		R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Steam Generation Saving		R 1,604,463.85	R 1,710,358.46	R 1,823,242.12	R 1,943,576.10	R 2,071,852.12	R 2,208,594.36	R 2,354,361.59	R 2,509,749.45	R 2,675,392.92	R 2,851,968.85
Escalation of Benefits		R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Total Benefits and Revenue	**R 0.00**	**R 16,475,330.35**	**R 18,291,374.61**	**R 20,311,075.12**	**R 22,557,509.90**	**R 25,056,388.31**	**R 27,836,352.21**	**R 30,929,311.59**	**R 34,370,818.70**	**R 38,200,485.13**	**R 42,462,446.67**
Cash Flow Before Taxes	**-R 66,821,000.00**	**R 13,952,346.16**	**R 15,424,366.39**	**R 17,053,133.14**	**R 18,855,327.98**	**R 20,849,391.67**	**R 23,055,706.34**	**R 25,496,795.97**	**R 28,197,546.98**	**R 31,185,450.77**	**R 34,490,870.28**
Income Tax Calculation											
Depreciation Expense		-R 13,364,200.00	-R 13,364,200.00	-R 13,364,200.00	-R 13,364,200.00	-R 13,364,200.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Operating Cost		-R 2,522,984.18	-R 2,867,008.21	-R 3,257,941.98	-R 3,702,181.92	-R 4,206,996.64	-R 4,780,645.87	-R 5,432,515.62	-R 6,173,271.72	-R 7,015,034.36	-R 7,971,576.39
Operating Benefits		R 16,475,330.35	R 18,291,374.61	R 20,311,075.12	R 22,557,509.90	R 25,056,388.31	R 27,836,352.21	R 30,929,311.59	R 34,370,818.70	R 38,200,485.13	R 42,462,446.67
Net Income Taxes	**R 0.00**	**-R 164,680.93**	**-R 576,846.59**	**-R 1,032,901.28**	**-R 1,537,515.83**	**-R 2,095,853.67**	**-R 6,455,597.77**	**-R 7,139,102.87**	**-R 7,895,313.15**	**-R 8,731,926.22**	**-R 9,657,443.68**
Cash Flow After Taxes	**-R 66,821,000.00**	**R 13,787,665.24**	**R 14,847,519.80**	**R 16,020,231.86**	**R 17,317,812.14**	**R 18,753,538.00**	**R 16,600,108.56**	**R 18,357,693.10**	**R 20,302,233.83**	**R 22,453,524.55**	**R 24,833,426.60**
Discounted Cash Flow (After Tax)	**-R 66,821,000.00**	**R 12,297,678.51**	**R 11,811,871.77**	**R 11,367,527.48**	**R 10,960,305.13**	**R 10,586,325.38**	**R 8,358,057.58**	**R 8,244,132.08**	**R 8,132,106.66**	**R 8,021,880.13**	**R 7,913,355.93**
Business Case Results:				**Assumptions:**							
NPV of Cash Flow	**R 30,872,240.65**			Cost Escalation Factor		6.60%					
IRR	**21.5%**			Benefit Escalation Factor		0.00%	Calculated at NERSA increases				
Profitability Index	**1.46**			Income Tax Rate		28.00%					
Simple Payback	4 Years 3 Months			WACC		12.12%					
Discounted Payback	6 Years 2 Months										

Table 4.18: FGR internal combustion generation - Financial calculation results

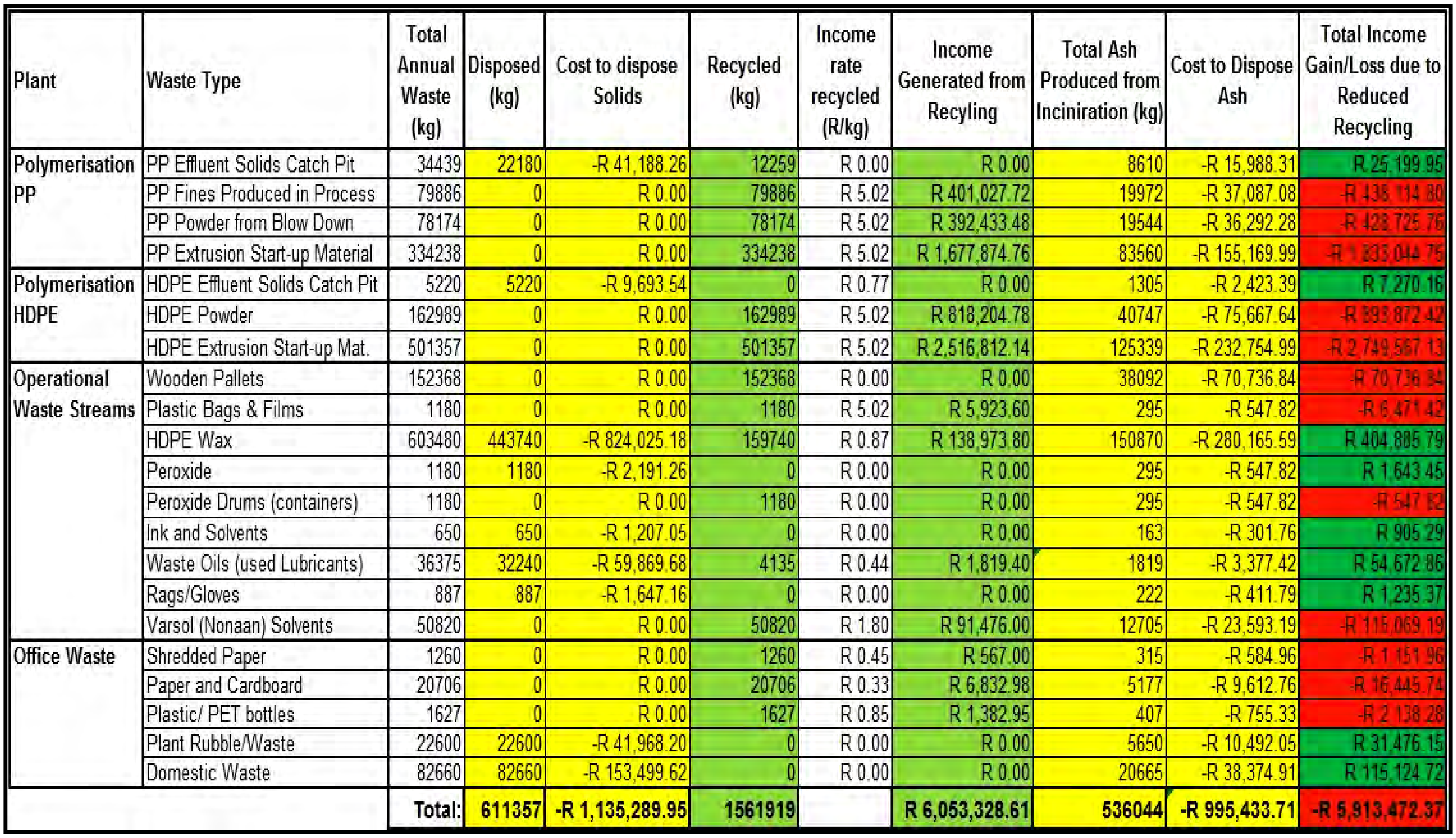
4.8.2. Generation using liquid and solid waste - financials

The incineration of solid waste materials will require a CHP incinerator which makes use of a steam turbine to generate the electrical power. This process is not conducive to irregular start and stop sequences due to long heating up and cooling times for the related equipment. The strategy to follow thus will be to run the generation units for extensive periods, twenty-four hours a day, seven days a week. The Mega-flex tariff applicable will thus be R0.77/kWh currently applicable to 2014.

The generation unit selected for this mode is System 2, utilizing a back-pressure turbine capable of delivering 3000kWh of electricity though an incinerator and boiler configuration. The total fuel capacity from solids and liquids has a potential to fuel such a unit to deliver 2125 kWh. This is only 70.8% of capacity. The financial model will thus be adjusted to run the plant full-time for 258 days of the year. The rest of the down-time can be utilized to stockpile fuel and conduct the needed maintenance on the boiler and incineration systems.

From table 4.16 it is clear that Safripol is focused on recycling, which is the preferred process to follow on up to 82% of the total solid and liquid waste streams. Only 18% on average, of the solid/liquid waste streams are disposed of at a cost to the company. This figure includes recycled metals which are not part of the study.

Focusing only on hydrocarbon waste (Solid/Liquid), the ratio between disposal and recycling is in the region of 28% disposal and 72% recycling. The table below provides the detail with regard to the financials of disposal versus recycling. This table includes the cost to dispose of the residue ash which is a deliverable (25% of initial fuel weight) from the incineration process.



Plant	Waste Type	Total Annual Waste (kg)	Disposed (kg)	Cost to dispose Solids	Recycled (kg)	Income rate recycled (R/kg)	Income Generated from Recyling	Total Ash Produced from Inciniration (kg)	Cost to Dispose Ash	Total Income Gain/Loss due to Reduced Recycling
Polymerisation PP	PP Effluent Solids Catch Pit	34439	22180	-R 41,188.26	12259	R 0.00	R 0.00	8610	-R 15,988.31	R 25,199.95
	PP Fines Produced in Process	79886	0	R 0.00	79886	R 5.02	R 401,027.72	19972	-R 37,087.08	-R 438,114.80
	PP Powder from Blow Down	78174	0	R 0.00	78174	R 5.02	R 392,433.48	19544	-R 36,292.28	-R 428,725.76
	PP Extrusion Start-up Material	334238	0	R 0.00	334238	R 5.02	R 1,677,874.76	83560	-R 155,169.99	-R 1,833,044.75
Polymerisation HDPE	HDPE Effluent Solids Catch Pit	5220	5220	-R 9,693.54	0	R 0.77	R 0.00	1305	-R 2,423.39	R 7,270.16
	HDPE Powder	162989	0	R 0.00	162989	R 5.02	R 818,204.78	40747	-R 75,667.64	-R 893,872.42
	HDPE Extrusion Start-up Mat.	501357	0	R 0.00	501357	R 5.02	R 2,516,812.14	125339	-R 232,754.99	-R 2,749,567.13
Operational Waste Streams	Wooden Pallets	152368	0	R 0.00	152368	R 0.00	R 0.00	38092	-R 70,736.84	-R 70,736.84
	Plastic Bags & Films	1180	0	R 0.00	1180	R 5.02	R 5,923.60	295	-R 547.82	-R 6,471.42
	HDPE Wax	603480	443740	-R 824,025.18	159740	R 0.87	R 138,973.80	150870	-R 280,165.59	R 404,885.79
	Peroxide	1180	1180	-R 2,191.26	0	R 0.00	R 0.00	295	-R 547.82	R 1,643.45
	Peroxide Drums (containers)	1180	0	R 0.00	1180	R 0.00	R 0.00	295	-R 547.82	-R 547.82
	Ink and Solvents	650	650	-R 1,207.05	0	R 0.00	R 0.00	163	-R 301.76	R 905.29
	Waste Oils (used Lubricants)	36375	32240	-R 59,869.68	4135	R 0.44	R 1,819.40	1819	-R 3,377.42	R 54,672.86
	Rags/Gloves	887	887	-R 1,647.16	0	R 0.00	R 0.00	222	-R 411.79	R 1,235.37
	Varsol (Nonaan) Solvents	50820	0	R 0.00	50820	R 1.80	R 91,476.00	12705	-R 23,593.19	-R 115,069.19
Office Waste	Shredded Paper	1260	0	R 0.00	1260	R 0.45	R 567.00	315	-R 584.96	-R 1,151.96
	Paper and Cardboard	20706	0	R 0.00	20706	R 0.33	R 6,832.98	5177	-R 9,612.76	-R 16,445.74
	Plastic/ PET bottles	1627	0	R 0.00	1627	R 0.85	R 1,382.95	407	-R 755.33	-R 2,138.28
	Plant Rubble/Waste	22600	22600	-R 41,968.20	0	R 0.00	R 0.00	5650	-R 10,492.05	R 31,476.15
	Domestic Waste	82660	82660	-R 153,499.62	0	R 0.00	R 0.00	20665	-R 38,374.91	R 115,124.72
		Total:	**611357**	**-R 1,135,289.95**	**1561919**		**R 6,053,328.61**	**536044**	**-R 995,433.71**	**-R 5,913,472.37**

Table 4.19: Safripol waste stream disposal vs. recycling, incinerated

The loss of income on recycled waste adds up to R5,913,472. This value will be included as an operational cost in income in the financial input model. The cost to dispose of ash balances out with the existing waste disposal costs and will be omitted from the model.

Maintenance cost on the turbine is calculated at R0.07 per kW generated and the maintenance factor on the boiler and incinerator is set at 2% of total investment costs. The turbine-generation set is calculated at a cost of R7,486 per kW generated. The stoker and boiler combination is installed at a cost of R20,116 per kW. The table below provides the information and details entered into the financial model.

Solid & Liquid Waste Incineration CHP											
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Total Installed Cost (ZAR/kW)	R 27,601.89	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Maximum Capacity (kW)	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00
Total Capital investment - Installed (ZAR)	R 82,825,786	0	0	0	0	0	0	0	0	0	0
Turbine genset cost (ZAR/kW)	R 7,486										
Stoker Boiler Cost (ZAR/kW)	R 20,116										
Total Electricity Generated Annual (kWh)	18,576,000	18,576,000	18,576,000	18,576,000	18,576,000	18,576,000	18,576,000	18,576,000	18,576,000	18,576,000	18,576,000
Genset Maintenance Factor (ZAR/kW)	R 0.07	R 0.08	R 0.08	R 0.09	R 0.10	R 0.10	R 0.11	R 0.12	R 0.12	R 0.13	R 0.14
Total Annualized Maintenance cost for Genset (ZAR)	R 1,380,197	R 1,471,290	R 1,568,395	R 1,671,909	R 1,782,255	R 1,899,884	R 2,025,276	R 2,158,944	R 2,301,435	R 2,453,329	R 2,615,249
Total Annualized Maintenance cost for Incinerator and Boiler (ZAR)	R 1,656,516	R 1,765,846	R 1,882,392	R 2,006,629	R 2,139,067	R 2,280,245	R 2,430,742	R 2,591,171	R 2,762,188	R 2,944,492	R 3,138,829
Operational Cost - Loss of Recycle Income(ZAR)	R 5,913,472	R 6,303,762	R 6,719,810	R 7,163,317	R 7,636,096	R 8,140,079	R 8,677,324	R 9,250,027	R 9,860,529	R 10,511,324	R 11,205,071
Inflation Rate (CPI)	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%
Cost of Electricity Annual Average (ZAR/kWh)	R 0.77	R 0.86	R 0.96	R 1.07	R 1.19	R 1.33	R 1.48	R 1.65	R 1.84	R 2.05	R 2.29
Income from Electrical Cost Avoidance	R 14,303,520	R 15,948,425	R 17,782,494	R 19,827,480	R 22,107,641	R 24,650,019	R 27,484,772	R 30,645,520	R 34,169,755	R 38,099,277	R 42,480,694
Annual Increase of Electricity cost	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%
Carbon CO_2 tax (ZAR/ton)	R 0	R 0	R 120	R 132	R 145	R 160	R 176	R 193	R 213	R 234	R 257
Total Saved Carbon tax (ZAR)	R 0	R 0	R 1,939,334	R 2,133,268	R 2,346,595	R 2,581,254	R 2,839,379	R 3,123,317	R 3,435,649	R 3,779,214	R 4,157,136
Carbon Intensity for Electricity Generation in RSA (kg/kWh)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Total Carbon Emmissions (ton/p.a.)	16,161.12	16,161.12	16,161.12	16,161.12	16,161.12	16,161.12	16,161.12	16,161.12	16,161.12	16,161.12	16,161.12
Carbon Tax Annual increase	0.0%	0.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%

Table 4.20: Waste incineration generation input into financial model

The simple payback is calculated to be eight years and four months. The discounted payback did not yield a result due to a negative Net Present Value.

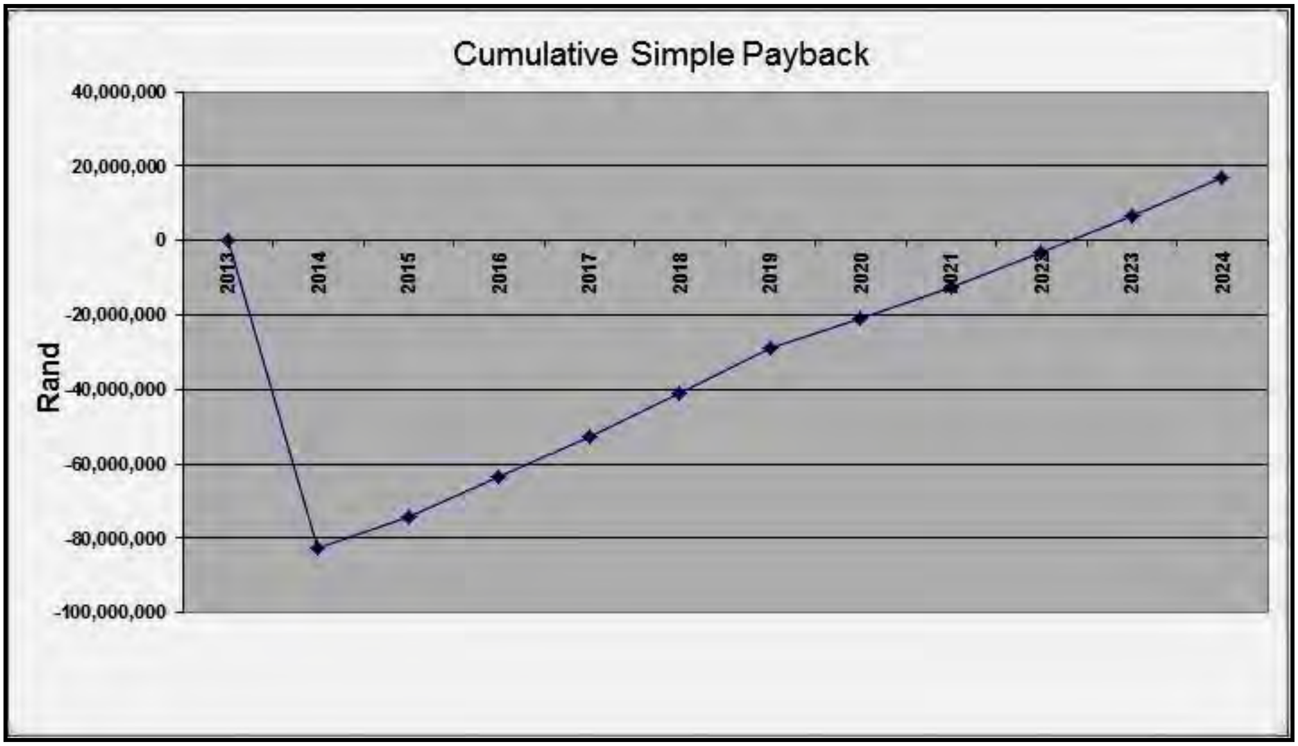


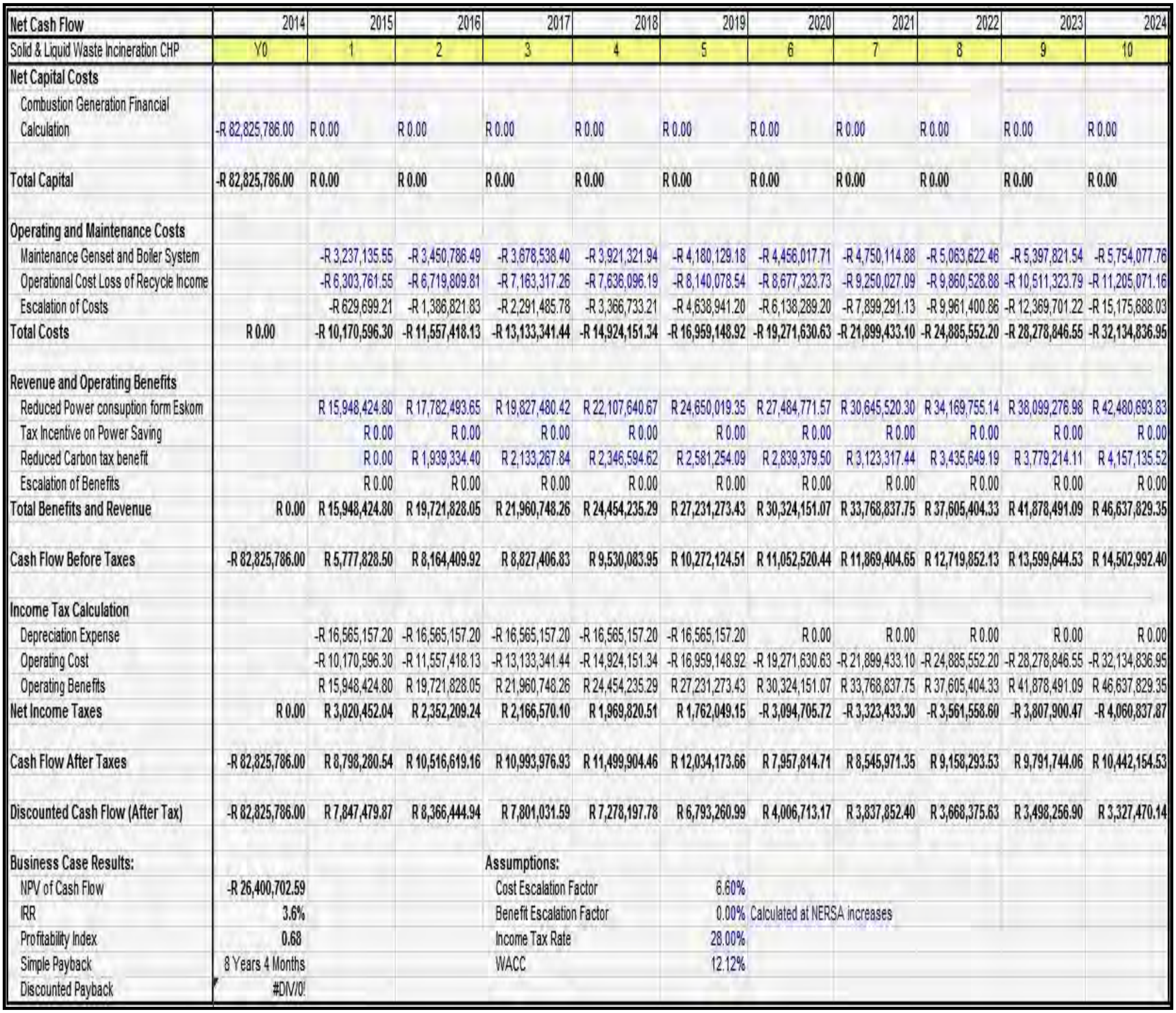
Figure 4.23: Simple payback for incineration generation

The depreciation of the capital investment is done over five years and the results indicated that this is not a feasible investment to embark on.

From the calculations in Table 4.21 the following financial results can be presented:

- Profitability Index = 0.68
- NPV of Cash Flow = Rm -26,400
- IRR = 3.6%

The main reason for the model not delivering positive investment results was found to be the loss in income on recycled waste. Should this value be omitted from the model the results showed a profitability index of 1.24 and an IRR of 17.1%. The table below provides the detail on the model based on the loss of recycling income.



Net Cash Flow	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Solid & Liquid Waste Incineration CHP	Y0	1	2	3	4	5	6	7	8	9	10
Net Capital Costs											
Combustion Generation Financial Calculation	-R 82,825,786.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Total Capital	**-R 82,825,786.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**	**R 0.00**
Operating and Maintenance Costs											
Maintenance Genset and Boiler System		-R 3,237,135.55	-R 3,450,786.49	-R 3,678,538.40	-R 3,921,321.94	-R 4,180,129.18	-R 4,456,017.71	-R 4,750,114.88	-R 5,063,622.46	-R 5,397,821.54	-R 5,754,077.76
Operational Cost Loss of Recycle Income		-R 6,303,761.55	-R 6,719,809.81	-R 7,163,317.26	-R 7,636,096.19	-R 8,140,078.54	-R 8,677,323.73	-R 9,250,027.09	-R 9,860,528.88	-R 10,511,323.79	-R 11,205,071.16
Escalation of Costs		-R 629,699.21	-R 1,386,821.83	-R 2,291,485.78	-R 3,366,733.21	-R 4,638,941.20	-R 6,138,289.20	-R 7,899,291.13	-R 9,961,400.86	-R 12,369,701.22	-R 15,175,688.03
Total Costs	**R 0.00**	**-R 10,170,596.30**	**-R 11,557,418.13**	**-R 13,133,341.44**	**-R 14,924,151.34**	**-R 16,959,148.92**	**-R 19,271,630.63**	**-R 21,899,433.10**	**-R 24,885,552.20**	**-R 28,278,846.55**	**-R 32,134,836.95**
Revenue and Operating Benefits											
Reduced Power consuption form Eskom		R 15,948,424.80	R 17,782,493.65	R 19,827,480.42	R 22,107,640.67	R 24,650,019.35	R 27,484,771.57	R 30,645,520.30	R 34,169,755.14	R 38,099,276.98	R 42,480,693.83
Tax Incentive on Power Saving		R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Reduced Carbon tax benefit		R 0.00	R 1,939,334.40	R 2,133,267.84	R 2,346,594.62	R 2,581,254.09	R 2,839,379.50	R 3,123,317.44	R 3,435,649.19	R 3,779,214.11	R 4,157,135.52
Escalation of Benefits		R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Total Benefits and Revenue	**R 0.00**	**R 15,948,424.80**	**R 19,721,828.05**	**R 21,960,748.26**	**R 24,454,235.29**	**R 27,231,273.43**	**R 30,324,151.07**	**R 33,768,837.75**	**R 37,605,404.33**	**R 41,878,491.09**	**R 46,637,829.35**
Cash Flow Before Taxes	**-R 82,825,786.00**	**R 5,777,828.50**	**R 8,164,409.92**	**R 8,827,406.83**	**R 9,530,083.95**	**R 10,272,124.51**	**R 11,052,520.44**	**R 11,869,404.65**	**R 12,719,852.13**	**R 13,599,644.53**	**R 14,502,992.40**
Income Tax Calculation											
Depreciation Expense		-R 16,565,157.20	-R 16,565,157.20	-R 16,565,157.20	-R 16,565,157.20	-R 16,565,157.20	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Operating Cost		-R 10,170,596.30	-R 11,557,418.13	-R 13,133,341.44	-R 14,924,151.34	-R 16,959,148.92	-R 19,271,630.63	-R 21,899,433.10	-R 24,885,552.20	-R 28,278,846.55	-R 32,134,836.95
Operating Benefits		R 15,948,424.80	R 19,721,828.05	R 21,960,748.26	R 24,454,235.29	R 27,231,273.43	R 30,324,151.07	R 33,768,837.75	R 37,605,404.33	R 41,878,491.09	R 46,637,829.35
Net Income Taxes	**R 0.00**	**R 3,020,452.04**	**R 2,352,209.24**	**R 2,166,570.10**	**R 1,969,820.51**	**R 1,762,049.15**	**-R 3,094,705.72**	**-R 3,323,433.30**	**-R 3,561,558.60**	**-R 3,807,900.47**	**-R 4,060,837.87**
Cash Flow After Taxes	**-R 82,825,786.00**	**R 8,798,280.54**	**R 10,516,619.16**	**R 10,993,976.93**	**R 11,499,904.46**	**R 12,034,173.66**	**R 7,957,814.71**	**R 8,545,971.35**	**R 9,158,293.53**	**R 9,791,744.06**	**R 10,442,154.53**
Discounted Cash Flow (After Tax)	**-R 82,825,786.00**	**R 7,847,479.87**	**R 8,366,444.94**	**R 7,801,031.59**	**R 7,278,197.78**	**R 6,793,260.99**	**R 4,006,713.17**	**R 3,837,852.40**	**R 3,668,375.63**	**R 3,498,256.90**	**R 3,327,470.14**
Business Case Results:				**Assumptions:**							
NPV of Cash Flow	-R 26,400,702.59			Cost Escalation Factor		6.60%					
IRR	3.6%			Benefit Escalation Factor		0.00%	Calculated at NERSA increases				
Profitability Index	0.68			Income Tax Rate		28.00%					
Simple Payback	8 Years 4 Months			WACC		12.12%					
Discounted Payback	#DIV/0!										

Table 4.21: Waste incineration generation financial model

4.9. Electricity generation from hydro-powered generators - financials

Water-driven generators to be selected for the Safripol manufacturing site are to be installed on cooling water and transport water systems. These systems need to be operational on a continuous basis. This infers that the generation from piped generators will be done on a continuous basis, only allowing down-time during plant shutdowns. The average time for a planned plant shutdown is a maximum of two weeks per year.

The total annual capacity is thus based on 50 weeks out of the total of 52 weeks (96%) in any given year, and the Mega-flex tariff applicable to this will be the current R0.77/kWh that is calculated for the year 2014. The maintenance costs for small turbine generators is between 1% and 4% of the total installed cost but, for the purposes of this study, the maintenance cost will be calculated at 2% of the total installed cost.

This form of power generation does not emit any fugitive gases and the CO tax savings will be incorporated as an additional income into the financial model. The input with regard to the capacity will be based on the total site capacity (228 kWh), although the smaller micro-generators are more expensive to install, the aim will be to concentrate on the bigger installations such as the cooling water return lines.

The capitalization of the assets will be calculated on the accelerated basis of three years (50%, 30% and 20%), because this type of power generation is included in the tax incentive scheme for renewable energy resources. The average installed cost will be based on R26, 117 per kW as per the quoted prices from Alternagy (Table 2.13).

The table below includes all the above-mentioned data which are entered into the financial input sheet.

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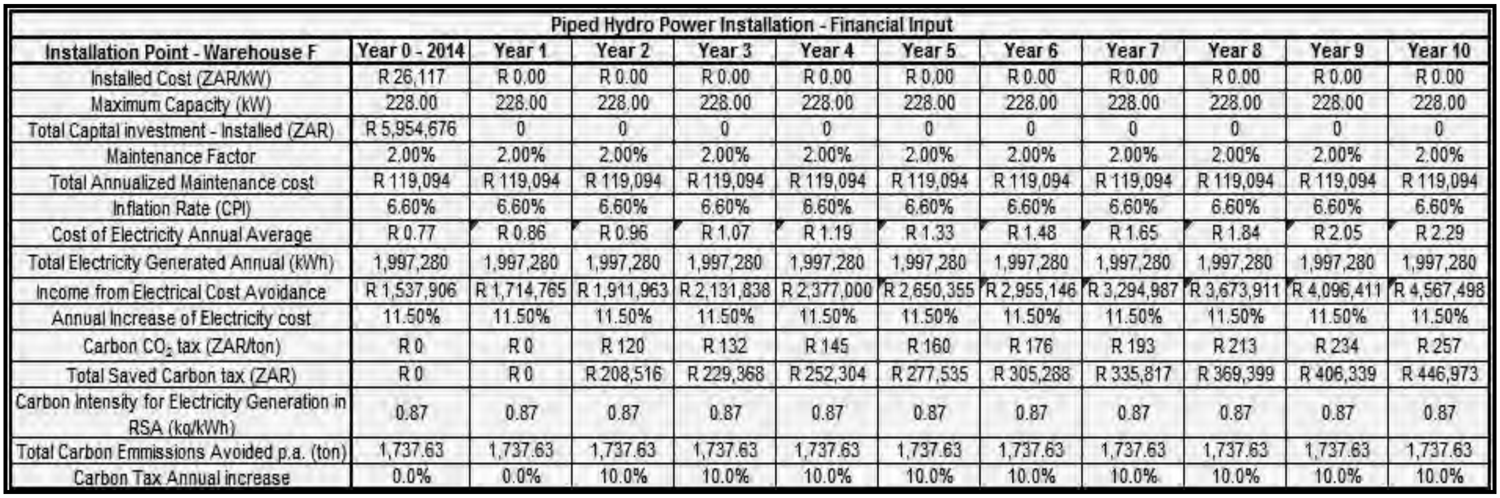


Piped Hydro Power Installation - Financial Input

Installation Point - Warehouse F	Year 0 - 2014	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Installed Cost (ZAR/kW)	R 26,117	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Maximum Capacity (kW)	228.00	228.00	228.00	228.00	228.00	228.00	228.00	228.00	228.00	228.00	228.00
Total Capital investment - Installed (ZAR)	R 5,954,676	0	0	0	0	0	0	0	0	0	0
Maintenance Factor	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%
Total Annualized Maintenance cost	R 119,094	R 119,094	R 119,094	R 119,094	R 119,094	R 119,094	R 119,094	R 119,094	R 119,094	R 119,094	R 119,094
Inflation Rate (CPI)	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%
Cost of Electricity Annual Average	R 0.77	R 0.86	R 0.96	R 1.07	R 1.19	R 1.33	R 1.48	R 1.65	R 1.84	R 2.05	R 2.29
Total Electricity Generated Annual (kWh)	1,997,280	1,997,280	1,997,280	1,997,280	1,997,280	1,997,280	1,997,280	1,997,280	1,997,280	1,997,280	1,997,280
Income from Electrical Cost Avoidance	R 1,537,906	R 1,714,765	R 1,911,963	R 2,131,838	R 2,377,000	R 2,650,355	R 2,955,146	R 3,294,987	R 3,673,911	R 4,096,411	R 4,567,498
Annual Increase of Electricity cost	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%
Carbon CO_2 tax (ZAR/ton)	R 0	R 0	R 120	R 132	R 145	R 160	R 176	R 193	R 213	R 234	R 257
Total Saved Carbon tax (ZAR)	R 0	R 0	R 208,516	R 229,368	R 252,304	R 277,535	R 305,288	R 335,817	R 369,399	R 406,339	R 446,973
Carbon Intensity for Electricity Generation in RSA (kg/kWh)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Total Carbon Emmissions Avoided p.a. (ton)	1,737.63	1,737.63	1,737.63	1,737.63	1,737.63	1,737.63	1,737.63	1,737.63	1,737.63	1,737.63	1,737.63
Carbon Tax Annual increase	0.0%	0.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%

Table 4.22: Hydro-power - Input into financial model

The resultant simple payback us calculated to be three years and one month and the discounted payback calculated to be four years and two months.

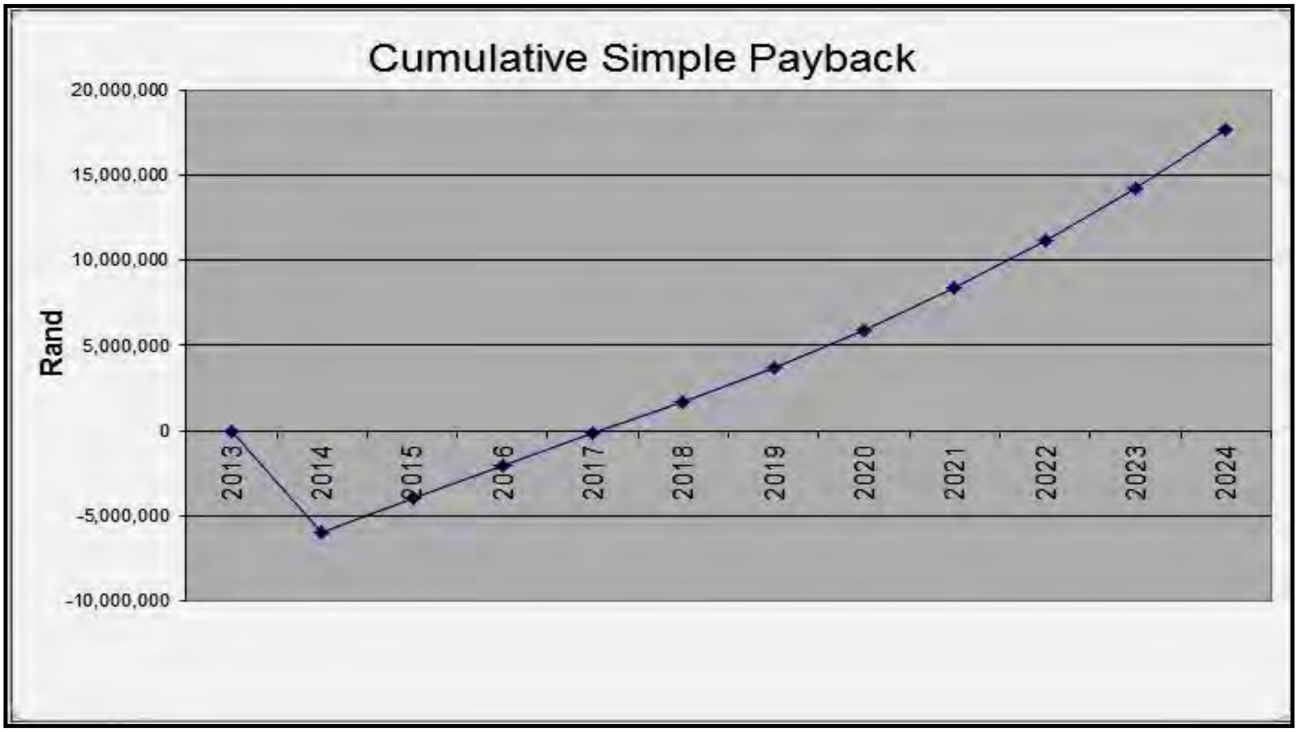
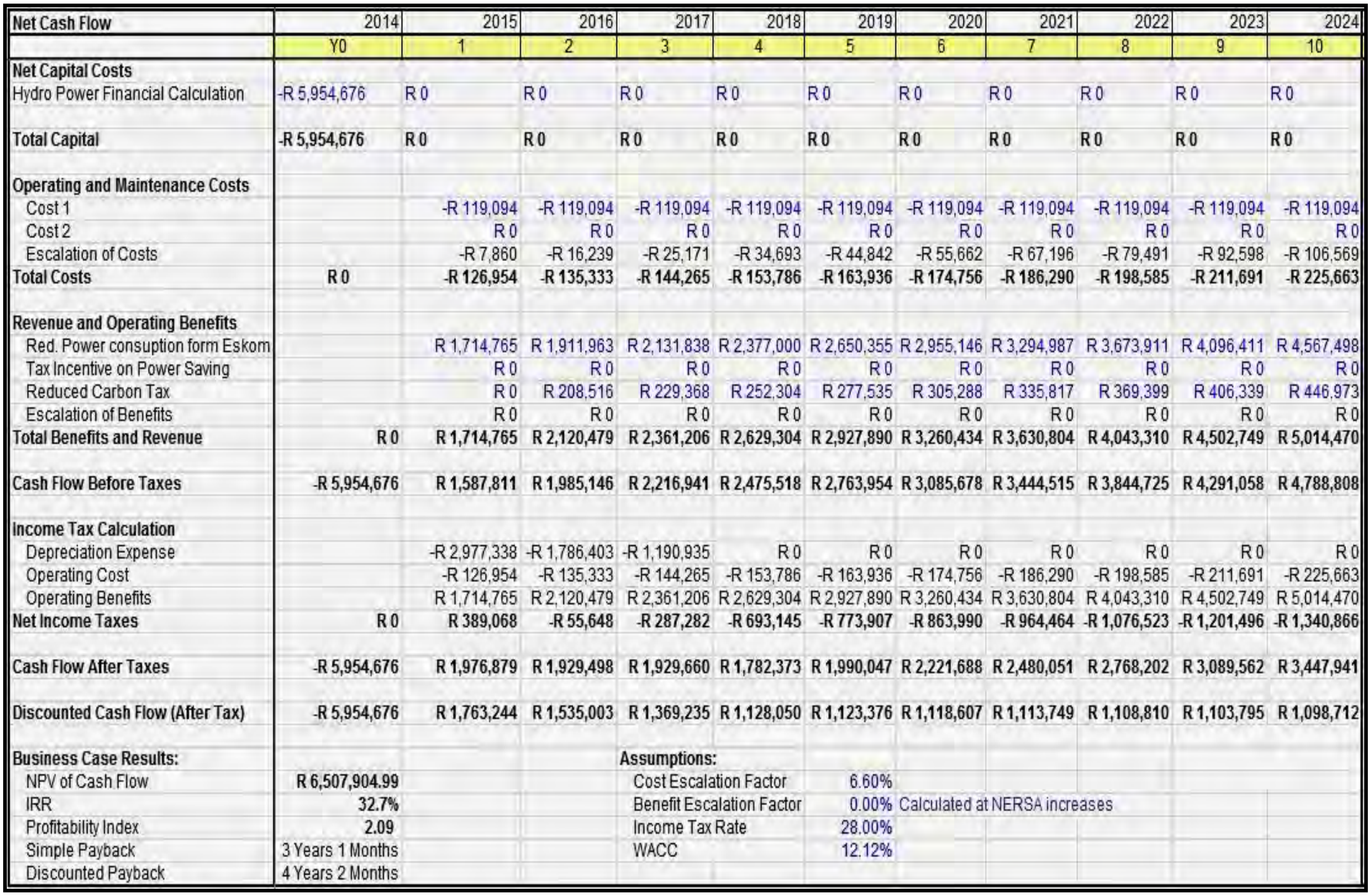


Figure 4.24: Simple payback for hydro power generation

The financial calculation yielded a Net Present Value of Rm 6, 507 which is quite considerable in relation to the total investment which is calculated to be just below 6 million Rand. The financial results:

- Profitability Index = 2.09
- NPV of Cash Flow = Rm 6, 507
- IRR = 32.7%



Net Cash Flow	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	Y0	1	2	3	4	5	6	7	8	9	10
Net Capital Costs											
Hydro Power Financial Calculation	-R 5,954,676	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Total Capital	**-R 5,954,676**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**
Operating and Maintenance Costs											
Cost 1		-R 119,094	-R 119,094	-R 119,094	-R 119,094	-R 119,094	-R 119,094	-R 119,094	-R 119,094	-R 119,094	-R 119,094
Cost 2		R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Escalation of Costs		-R 7,860	-R 16,239	-R 25,171	-R 34,693	-R 44,842	-R 55,662	-R 67,196	-R 79,491	-R 92,598	-R 106,569
Total Costs	**R 0**	**-R 126,954**	**-R 135,333**	**-R 144,265**	**-R 153,786**	**-R 163,936**	**-R 174,756**	**-R 186,290**	**-R 198,585**	**-R 211,691**	**-R 225,663**
Revenue and Operating Benefits											
Red. Power consuption form Eskom		R 1,714,765	R 1,911,963	R 2,131,838	R 2,377,000	R 2,650,355	R 2,955,146	R 3,294,987	R 3,673,911	R 4,096,411	R 4,567,498
Tax Incentive on Power Saving		R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Reduced Carbon Tax		R 0	R 208,516	R 229,368	R 252,304	R 277,535	R 305,288	R 335,817	R 369,399	R 406,339	R 446,973
Escalation of Benefits		R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Total Benefits and Revenue	**R 0**	**R 1,714,765**	**R 2,120,479**	**R 2,361,206**	**R 2,629,304**	**R 2,927,890**	**R 3,260,434**	**R 3,630,804**	**R 4,043,310**	**R 4,502,749**	**R 5,014,470**
Cash Flow Before Taxes	**-R 5,954,676**	**R 1,587,811**	**R 1,985,146**	**R 2,216,941**	**R 2,475,518**	**R 2,763,954**	**R 3,085,678**	**R 3,444,515**	**R 3,844,725**	**R 4,291,058**	**R 4,788,808**
Income Tax Calculation											
Depreciation Expense		-R 2,977,338	-R 1,786,403	-R 1,190,935	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Operating Cost		-R 126,954	-R 135,333	-R 144,265	-R 153,786	-R 163,936	-R 174,756	-R 186,290	-R 198,585	-R 211,691	-R 225,663
Operating Benefits		R 1,714,765	R 2,120,479	R 2,361,206	R 2,629,304	R 2,927,890	R 3,260,434	R 3,630,804	R 4,043,310	R 4,502,749	R 5,014,470
Net Income Taxes	**R 0**	**R 389,068**	**-R 55,648**	**-R 287,282**	**-R 693,145**	**-R 773,907**	**-R 863,990**	**-R 964,464**	**-R 1,076,523**	**-R 1,201,496**	**-R 1,340,866**
Cash Flow After Taxes	**-R 5,954,676**	**R 1,976,879**	**R 1,929,498**	**R 1,929,660**	**R 1,782,373**	**R 1,990,047**	**R 2,221,688**	**R 2,480,051**	**R 2,768,202**	**R 3,089,562**	**R 3,447,941**
Discounted Cash Flow (After Tax)	**-R 5,954,676**	**R 1,763,244**	**R 1,535,003**	**R 1,369,235**	**R 1,128,050**	**R 1,123,376**	**R 1,118,607**	**R 1,113,749**	**R 1,108,810**	**R 1,103,795**	**R 1,098,712**
Business Case Results:				**Assumptions:**							
NPV of Cash Flow	**R 6,507,904.99**			Cost Escalation Factor		6.60%					
IRR	**32.7%**			Benefit Escalation Factor		0.00%	Calculated at NERSA increases				
Profitability Index	**2.09**			Income Tax Rate		28.00%					
Simple Payback	3 Years 1 Months			WACC		12.12%					
Discounted Payback	4 Years 2 Months										

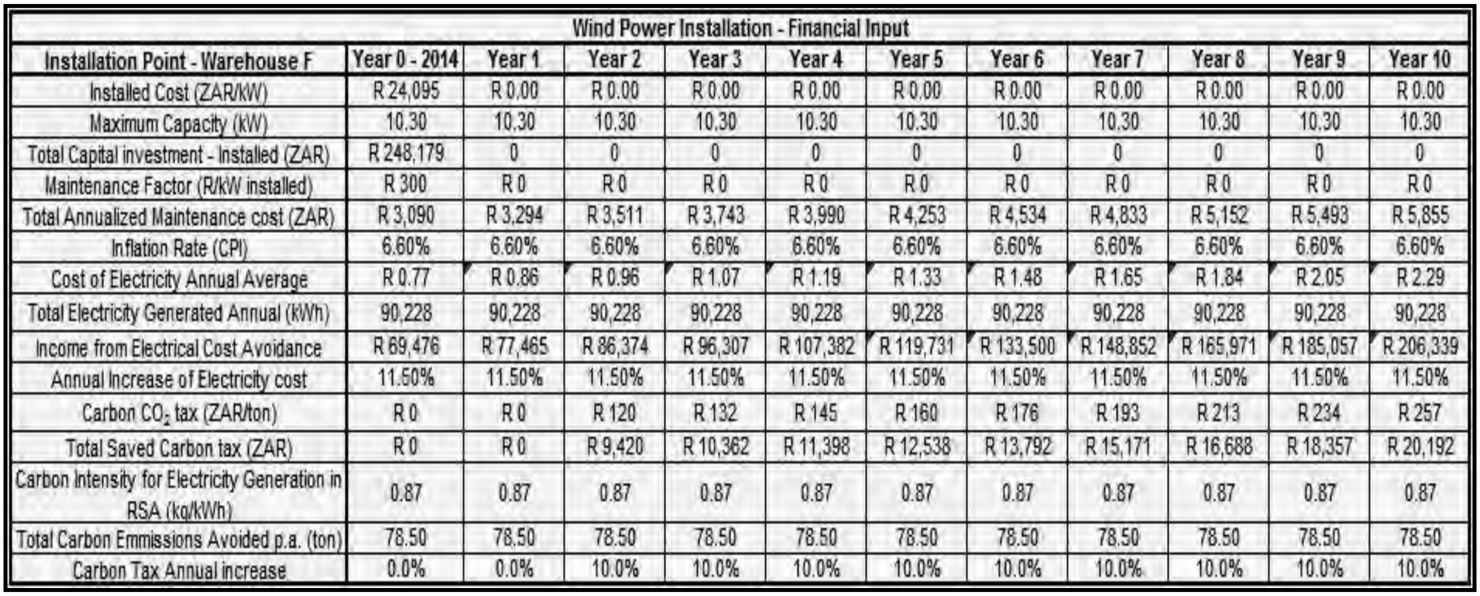
Table 4.23: Hydro-power – Financial results

4.10. Electricity generation from wind-powered generators - financials

Wind-driven power generators applicable to the Safripol scenario will be based on the generation potential from the exhaust fans on the relevant conveying and drying lines. These installation points in total provide a maximum generation capacity of 10 kW. The average cost of the installations is set at R24 095 per kW derived from the values in table 2.14.

Similar to hydro-power generation, this power-generation process does not emit any fugitive gases. The CO tax savings will be incorporated as an additional income into the financial model. The input with regard to the capacity will be based on the total site capacity (10.3 kWh). Operation and maintenance costs are set at R300 per kW installed over a period of a year.

The annual generation capacity is also based on the same online time of 96% of the year, similar to the Hydro generation model. The Cost of electricity is also set at R0.77 kWh and the depreciation calculation is also done over three years.



Wind Power Installation - Financial Input											
Installation Point - Warehouse F	Year 0 - 2014	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Installed Cost (ZAR/kW)	R 24,095	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00	R 0.00
Maximum Capacity (kW)	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30
Total Capital investment - Installed (ZAR)	R 248,179	0	0	0	0	0	0	0	0	0	0
Maintenance Factor (R/kW installed)	R 300	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Total Annualized Maintenance cost (ZAR)	R 3,090	R 3,294	R 3,511	R 3,743	R 3,990	R 4,253	R 4,534	R 4,833	R 5,152	R 5,493	R 5,855
Inflation Rate (CPI)	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%	6.60%
Cost of Electricity Annual Average	R 0.77	R 0.86	R 0.96	R 1.07	R 1.19	R 1.33	R 1.48	R 1.65	R 1.84	R 2.05	R 2.29
Total Electricity Generated Annual (kWh)	90,228	90,228	90,228	90,228	90,228	90,228	90,228	90,228	90,228	90,228	90,228
Income from Electrical Cost Avoidance	R 69,476	R 77,465	R 86,374	R 96,307	R 107,382	R 119,731	R 133,500	R 148,852	R 165,971	R 185,057	R 206,339
Annual Increase of Electricity cost	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%	11.50%
Carbon CO_2 tax (ZAR/ton)	R 0	R 0	R 120	R 132	R 145	R 160	R 176	R 193	R 213	R 234	R 257
Total Saved Carbon tax (ZAR)	R 0	R 0	R 9,420	R 10,362	R 11,398	R 12,538	R 13,792	R 15,171	R 16,688	R 18,357	R 20,192
Carbon Intensity for Electricity Generation in RSA (kg/kWh)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Total Carbon Emmissions Avoided p.a. (ton)	78.50	78.50	78.50	78.50	78.50	78.50	78.50	78.50	78.50	78.50	78.50
Carbon Tax Annual increase	0.0%	0.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%

Table 4.24: Wind generation – input into financial model

The results from the financial model showed a simple payback in only two years and ten months. Discounted payback is done over three years and nine months.

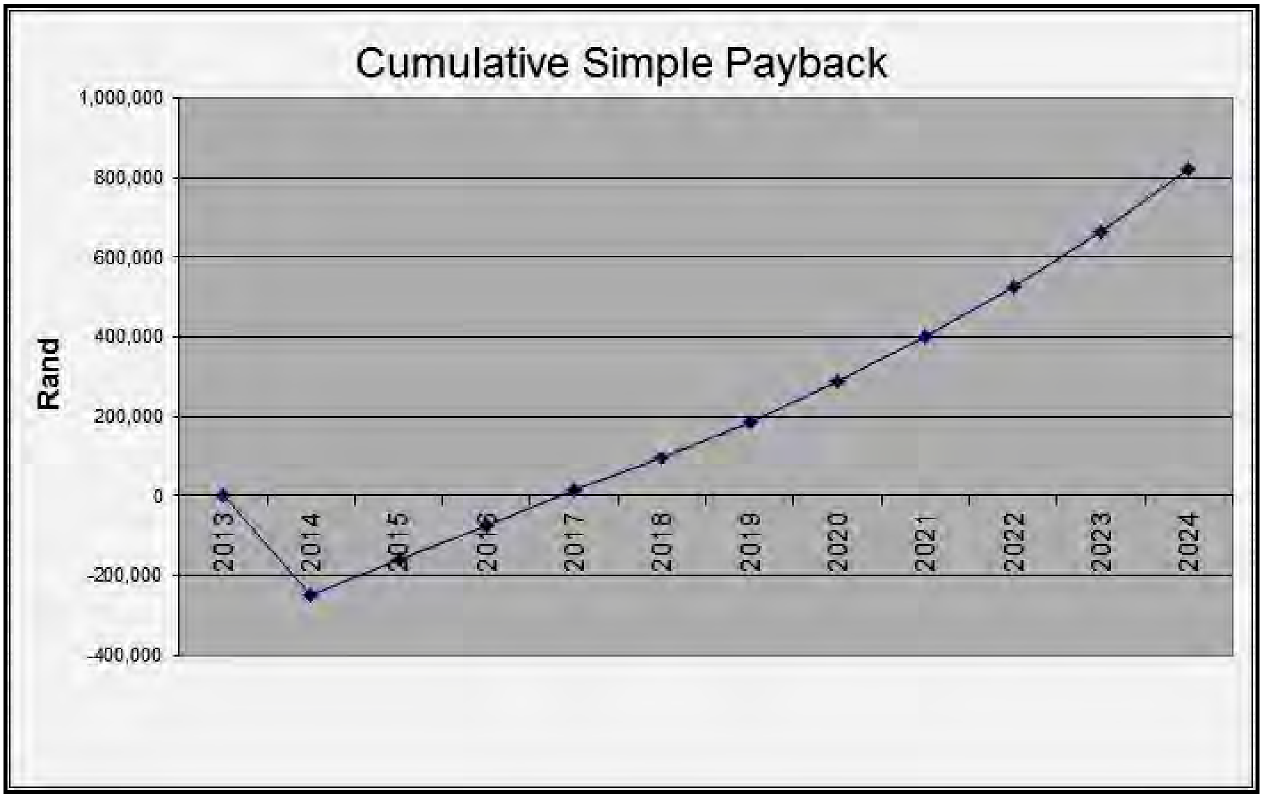
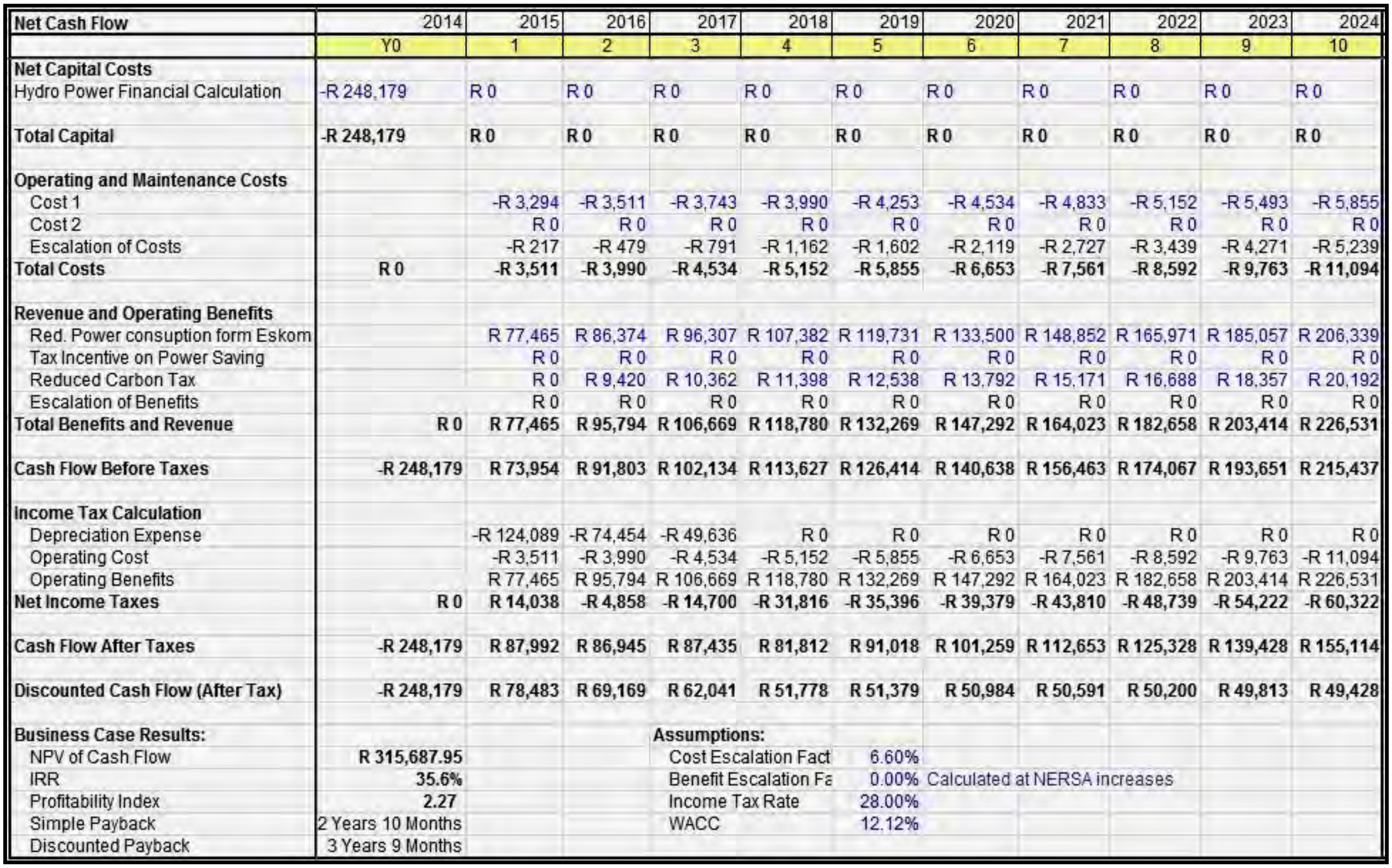


Figure 4.25: Simple payback for wind-power generation

The financial calculations on wind power generation delivered a Net Present Value of R315, 687.95 which is very good considering the total investment which is calculated to be around R250, 000.

The financial results:

- Profitability Index = 2.27
- NPV of Cash Flow = R315, 687.95
- IRR = 35.6%



Net Cash Flow	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	Y0	1	2	3	4	5	6	7	8	9	10
Net Capital Costs											
Hydro Power Financial Calculation	-R 248,179	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Total Capital	**-R 248,179**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**	**R 0**
Operating and Maintenance Costs											
Cost 1		-R 3,294	-R 3,511	-R 3,743	-R 3,990	-R 4,253	-R 4,534	-R 4,833	-R 5,152	-R 5,493	-R 5,855
Cost 2		R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Escalation of Costs		-R 217	-R 479	-R 791	-R 1,162	-R 1,602	-R 2,119	-R 2,727	-R 3,439	-R 4,271	-R 5,239
Total Costs	**R 0**	**-R 3,511**	**-R 3,990**	**-R 4,534**	**-R 5,152**	**-R 5,855**	**-R 6,653**	**-R 7,561**	**-R 8,592**	**-R 9,763**	**-R 11,094**
Revenue and Operating Benefits											
Red. Power consuption form Eskom		R 77,465	R 86,374	R 96,307	R 107,382	R 119,731	R 133,500	R 148,852	R 165,971	R 185,057	R 206,339
Tax Incentive on Power Saving		R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Reduced Carbon Tax		R 0	R 9,420	R 10,362	R 11,398	R 12,538	R 13,792	R 15,171	R 16,688	R 18,357	R 20,192
Escalation of Benefits		R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Total Benefits and Revenue	**R 0**	**R 77,465**	**R 95,794**	**R 106,669**	**R 118,780**	**R 132,269**	**R 147,292**	**R 164,023**	**R 182,658**	**R 203,414**	**R 226,531**
Cash Flow Before Taxes	**-R 248,179**	**R 73,954**	**R 91,803**	**R 102,134**	**R 113,627**	**R 126,414**	**R 140,638**	**R 156,463**	**R 174,067**	**R 193,651**	**R 215,437**
Income Tax Calculation											
Depreciation Expense		-R 124,089	-R 74,454	-R 49,636	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Operating Cost		-R 3,511	-R 3,990	-R 4,534	-R 5,152	-R 5,855	-R 6,653	-R 7,561	-R 8,592	-R 9,763	-R 11,094
Operating Benefits		R 77,465	R 95,794	R 106,669	R 118,780	R 132,269	R 147,292	R 164,023	R 182,658	R 203,414	R 226,531
Net Income Taxes	**R 0**	**R 14,038**	**-R 4,858**	**-R 14,700**	**-R 31,816**	**-R 35,396**	**-R 39,379**	**-R 43,810**	**-R 48,739**	**-R 54,222**	**-R 60,322**
Cash Flow After Taxes	**-R 248,179**	**R 87,992**	**R 86,945**	**R 87,435**	**R 81,812**	**R 91,018**	**R 101,259**	**R 112,653**	**R 125,328**	**R 139,428**	**R 155,114**
Discounted Cash Flow (After Tax)	**-R 248,179**	**R 78,483**	**R 69,169**	**R 62,041**	**R 51,778**	**R 51,379**	**R 50,984**	**R 50,591**	**R 50,200**	**R 49,813**	**R 49,428**
Business Case Results:				**Assumptions:**							
NPV of Cash Flow	**R 315,687.95**			Cost Escalation Fact		6.60%					
IRR	**35.6%**			Benefit Escalation Fa		0.00%	Calculated at NERSA increases				
Profitability Index	**2.27**			Income Tax Rate		28.00%					
Simple Payback	2 Years 10 Months			WACC		12.12%					
Discounted Payback	3 Years 9 Months										

Table 4.25: Wind-generation – Financial model

4.11.Chapter four - closure

Chapter four provided all data as captured from the existing Safripol reporting structures. The data have been incorporated in accordance to the design stipulated in chapter three. The exact financial calculation tools utilized in the Safripol business provided the means to determine the financial feasibility for each of the four generation techniques. The next chapter will discuss the results and compare all four generation techniques in order to comprehend how they can aid in generating power independent of ESKOM in a responsible manner.

CHAPTER FIVE

Results, discussion and interpretation

5.1. Chapter Five - Introduction

Chapter five provides an understanding with regard to the results from the empirical investigation. The chapter will focus on bringing all the different power generation techniques, studied in this case study, in perspective. This will be done with regard to the generation potential and the financial feasibility of the different generation techniques.

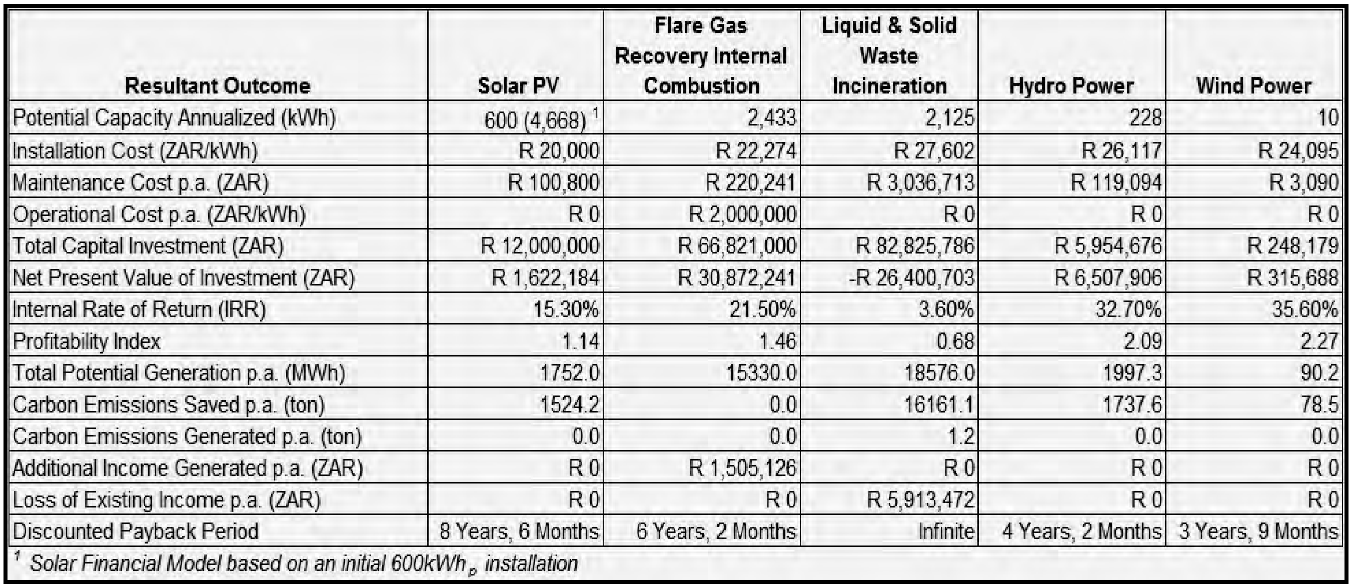
Alternative solutions for power generation will have a definite effect on Safripol's socio-economic and public image. The opportunity to lessen the dependency on ESKOM as a sole power supplier has been taken into consideration during the interpretation process. Other underlying environmental effects that may arise from incineration and combustion processes are elaborated on in the latter part of chapter 5.

All of the alternative techniques studied thus far were presented separately, but this chapter will allow for the techniques to be tabled alongside each other in order to reach the best possible solution for Safripol.

5.2. Results summary – capacity and financials

Table 5.1 includes the summarized results that were obtained from chapter four. The total generation capacity derived from alternative generation techniques calculated to considerable 9,464 kWh. This is almost half of the current peak demand from the production facility.

The individual ESKOM tariffs applicable to each generation technique are omitted from the summarized table below. This value was calculated according to the best possible combination with the applicable generation techniques. All other applicable variables such as the financial returns and generation capacities are included in table 5.1.



Resultant Outcome	Solar PV	Flare Gas Recovery Internal Combustion	Liquid & Solid Waste Incineration	Hydro Power	Wind Power
Potential Capacity Annualized (kWh)	600 (4,668) [1]	2,433	2,125	228	10
Installation Cost (ZAR/kWh)	R 20,000	R 22,274	R 27,602	R 26,117	R 24,095
Maintenance Cost p.a. (ZAR)	R 100,800	R 220,241	R 3,036,713	R 119,094	R 3,090
Operational Cost p.a. (ZAR/kWh)	R 0	R 2,000,000	R 0	R 0	R 0
Total Capital Investment (ZAR)	R 12,000,000	R 66,821,000	R 82,825,786	R 5,954,676	R 248,179
Net Present Value of Investment (ZAR)	R 1,622,184	R 30,872,241	-R 26,400,703	R 6,507,906	R 315,688
Internal Rate of Return (IRR)	15.30%	21.50%	3.60%	32.70%	35.60%
Profitability Index	1.14	1.46	0.68	2.09	2.27
Total Potential Generation p.a. (MWh)	1752.0	15330.0	18576.0	1997.3	90.2
Carbon Emissions Saved p.a. (ton)	1524.2	0.0	16161.1	1737.6	78.5
Carbon Emissions Generated p.a. (ton)	0.0	0.0	1.2	0.0	0.0
Additional Income Generated p.a. (ZAR)	R 0	R 1,505,126	R 0	R 0	R 0
Loss of Existing Income p.a. (ZAR)	R 0	R 0	R 5,913,472	R 0	R 0
Discounted Payback Period	8 Years, 6 Months	6 Years, 2 Months	Infinite	4 Years, 2 Months	3 Years, 9 Months

[1] *Solar Financial Model based on an initial 600kWh$_p$ installation*

Table 5.1: Generation results summarized

Solar PV financials are based on a 600kWh$_p$ installation but, it does not affect any of the financial decision indicators, although the site has a total capacity of 4.668MWh. A bigger installation will only change the total installation cost and present a higher NPV in relation to the initial investment. The annual Solar PV generation will be higher should the initial investment be larger.

Generation by means of Solar PV allows for phased installations which provide the advantage of starting with a smaller initial investment (R12mil) for a 600kWp plant. To install the total capacity of a 4668kWp plant will require a massive R93.36 million investment. Phased installations over a period of time will require vigilant planning with regard to the electrical control equipment to ensure that adaptability is possible, with increased power sourced from the solar arrays.

From table 5.1 it is clear that the only power generation technique that is not economically viable is the liquid / solid waste incineration process. This is mainly due to a major loss in income from the recycling programme that is currently in place at Safripol. Recycling solid plastic waste is still delivering a good income to the company which cannot be disregarded. CHP combustion generation is done with a closed-loop steam system and this forfeits the supplementary advantage of additional steam generation for further plant use.

The opportunity still exists to obtain a single liquid incinerator to burn the liquid wastes such as the wax and lubrication oils, which is sold off at a fifth of the price currently obtained from plastic wastes. This is definitely a subject for further investigation.

Both wind and water-powered generators were able to deliver generation of electricity at 96% of the time, for the full year. Tallying the generated power over a one-year period is the main reason why the return on investment (IRR) was superior to the other generation techniques. The hourly capacity, however, is not as substantial compared to the other techniques researched.

Wind-driven power generation was limited to transport and drying systems and the capacity only amounted to a maximum of 10.3 kWh. This begs the question as to whether it is worthwhile committing the resources to gain such a small amount of power generation. The site location, according to the average wind-speed map of South Africa, suggested that the site is not suitable for large-scale wind power generation but, the high structures on the plant might allow for further investigation.

Power generation from flare gas recycling systems provided the most significant return in both the capacity and financial return fields. The total of 2.433 MWh is more that 12% of the facility’s total demand (20 MWh) figure. Power generation from internal combustion engines allows for a very dynamic start-up procedure that can cater for power generation during peak demand periods and seasons. This advantage led to a higher calculated electricity cost in the financial model, which aided the IRR value (21.5%).

The use of internal combustion units allows for a further advantage in generating low pressure steam, which provides an additional income to the plant in the form of reduced steam costs. The liquid ring recycle compressors consume extra electrical power but this has been incorporated into the financial model as operating costs. This investment still provided an impressive profitability index of 1.46.

Hydro-power generation provided very good returns on the investment calculations although the total hourly generation potential only amounted to 228kWh. The opportunity to generate power 96% of the year, allowed for an annual total of 1997.3 MW which is more than the annual total calculated for Solar PV at 1752 MW.

Considering that the size of Solar PV was based on a 600 kWp plant, it proves that a Hydro plant will deliver more power than a Solar PV plant that is twice the size. From the results the installation points on the cooling water systems provided the best installation points.

5.3. Results summary – environmental concerns

Only the internal combustion and incineration processes are not considered to be forms of renewable energy. All other means of power generation, in this case study, are forms of renewable energy production. This was specifically of value during the financial calculations, since these forms of power generation accommodated an accelerated depreciation process and savings in the form of carbon taxes.

The real value, however, from a socio-economic approach, is the opportunity for the business to reduce its environmental footprint by reducing the need to obtain power from ESKOM. The incineration processes will reduce landfill amounts from solid and liquid waste streams but in turn produce other fugitive emissions. These emissions are much lower than the equivalent coal-based power generation from ESKOM.

The incineration processes generate ash and other forms of solid waste. This will require disposal in landfill sites but in general, these categories of waste are considered more environmentally friendly than the current chemical waste streams that require treatment before disposal.

Internal combustion generation will eliminate the need to flare propylene and ethylene gas through the two flare systems. During flare incidents the process requires steam to reduce carbon-rich smoke from entering the atmosphere. By diverting this fuel source through internal combustion engines, the exhaust systems will further reduce the steam consumption of the facility and reduce carbon rich smoke from entering the air.

5.4. Results validation

An independent company (SACE – South African Clean Energy Solutions Ltd.) has been invited to the Sasolburg manufacturing site to verify the feasibility of the Solar PV installation. The company immediately took an interest in getting involved with a Solar PV rooftop installation project at Safripol and delivered the following proposal:

- SACE will be able to install a 1MW solar array on a portion of the warehouse roofing system.
- They would procure and construct the PV plant at no cost to Safripol.
- SACE will maintain and operate the plant at no cost to Safripol.
- Safripol will need to purchase all the generated power from the PV array at the same price as currently charged by ESKOM.
- All of the carbon tax benefits can be claimed by Safripol which will be a financial benefit.

From the above-mentioned business proposal it can be derived that an independent company has built a business model that will be able to deliver financial returns to their own business. They are able to achieve a sustainable return on the solar installation investment by only matching the current (2014) cost of electricity from ESKOM.

Another validation of the feasibility of power generation with solar PV was obtained by reviewing a case study presented by Sunpower Corporation on a similar type of solar

PV system. The project was completed in September 2011 at the Marine Corps Ground Combat Center in Twenty-nine Palms, California, USA. The rooftop and shade structures were covered with 4680 solar PV panels and the total generation added to 1.5 MWp. The benefits of this system include:

- Offset of a total 18.5 kilo ton of CO2 emissions over the 25 year lifetime of the system;
- Financial saving of $3.2 million over the lifetime of the project; and
- 1,1million kWh of renewable clean energy generated for the system in one year. (Sunpower Corp et al. 2012)

5.5. Chapter five - closure

The results tabled in this chapter provide a complete overview of all four alternative generation techniques that are possible at Safripol. The total capacity and financial indicators are presented alongside one another in order to bring the possible solutions into perspective. Chapter six presents the answer to the problem statement as detailed in chapter one. Other recommendations elaborate on secondary solutions that can be integrated to form a comprehensive mitigating response to the rising electricity costs as supplied by ESKOM.

CHAPTER SIX

Conclusion and recommendations

6.1. Chapter Six - Introduction

Chapter six aims to present the best possible recommendations with regard to alternative power producing solutions for Safripol. The results from the study have been listed and discussed in detail in the previous two chapters but this chapter will elaborate on selecting the most practical and feasible power solution for Safripol.

The conclusion provides closure to this chapter and also to the case study. This provides insight into what learnings had been gained and then highlight further fields of detailed study that may be applicable to newer technologies that are currently in their infant stages of development.

6.2. Conclusion

The study provided a number of solutions which can be invested in, without changing the business model of the current Safripol operations. All the proposed solutions are linked to resources currently available at the Sasolburg manufacturing site.

Future expectations are that electrical costs are set to increase at an accelerated pace which will force Safripol to either cut its profit margins or seek other means of power generation. International imported plastics will remain a tough market competitor for Safripol and in order for the business to capitalize on new market shares presenting itself in the Southern African market, the company will need to expand its operations.

The opportunity to generate a portion of Safripol’s electrical supply will enable the company to capitalize on new business opportunities by means of small-scale expansions to the production facility.

6.2.1. Solar photo voltaic electricity generation

The total Solar PV generation potential calculated to prevalent aggregate of possible power generation of 4,668kWp is quite substantial, making up 23.3% of the existing maximum power consumption currently applicable to the Sasolburg manufacturing facility.

Cost to produce solar PV panels is predicted to continue a downward trend for at least the next five years. New local PV manufacturing companies focus mainly on delivering high quality solar panels to the South African market which will be stimulated by the Renewable Energy programme by the South African Government. International Solar PV panel producers still have to overcome a weak local currency but, having panels manufactured in South Africa will assist in continuing the downward trend in cost of this technology.

6.2.2. Excess hydrocarbon waste utilized for combustion generation

Power generation from internal combustion also provides a great opportunity that cannot be overlooked. The total capacity of 2,433kWh amounts to 12.2% of the total site consumption but, this technology will require a capital investment of more than R66 million. Although the IRR is calculated to be 21.5%, the need to drive compressors will add to the existing power consumption of the site. This is thus a secondary solution to alternative power generation for Safripol.

Solid hydrocarbon waste did not yield any financially feasible results due to the current income from the recycling processes that are in place at Safripol. The opportunity still exists to investigate the wax waste streams which can be utilized to burn off in burners which can produce steam. The study has listed the wax part of the solid and liquid waste streams but, this resource can be isolated to act as a fuel source completely on its own.

6.2.3. Kinetic energy harnessed to drive turbine generators

Hydro- and wind-driven power generation delivered the highest IRR values with a very small generation capacity. It is therefore not really worth the effort to embark on these investments since the capacity is just too low to make an impact on the existing power costing predicament that Safripol faces. In total it will not reduce the reliance on ESKOM for electrical power.

It may be feasible for Safripol to invest in these technologies merely because of the small amounts of capital investment needed and the high returns on the investments (IRR of 32.7% and 35.6%).

Wind generation may be able to generate more power than is expected from the site location. There are a number of tall structures at the facility that will be able to host a small VAWT (such as the unit displayed in Fig 2.26), which can be used to pilot a larger scale generation set should it be deemed successful.

6.3. Recommendations

The best solution for Safripol's alternative power solution is without doubt Solar PV power generation. This technology has the least impact on the existing processes and delivers a clean and sustainable power solution that will add value to the company's public perception.

The possibility to implement a large power generation system, in a phased progression, affords the opportunity to lessen the financial strain of a large capital investment. This will allow the company to learn more about this technology and local Solar PV producers as time passes.

Solar PV power is set to become a major role player in South Africa’s renewable energy plan, and this makes it the ideal time for Safripol to join this lucrative power-generation solution.

6.3.1. Recommendations for further research

From this case study it was found that many similar plants in the USA and Europe utilize FGR units to recover hydrocarbon gases, not to drive power plants but rather to redirect flare gas back to recovery plants which treats the gases in order to re-use it in the polymer processes. The flaring of hydrocarbon gases occurs at random intervals and is quite unpredictable but, there is the possibility to start the liquid ring recovery compressors only during the flaring incidents.

This will eliminate the need to run recycle compressors continuously, reducing the electrical consumption of these units. This is a field that needs to be studied further in order to understand the opportunities that may be captured from the FGR systems, and how it will benefit Safripol.

While studying the air-conveying lines it was found that the transport pipes contain a lot of static electricity. This is a major source of electrical power but, unfortunately at the time of this study, no technology exists to harness this amount of static energy. Only a number of universities in the USA and Europe are currently experimenting with small (milli-volts) projects. Once this technology can be applied on an industrial scale, it can be re-visited in order to tap into this electrical power source.

6.4. Learnings

The most significant learning benefit to emerge from this study was most definitely the amount of power that can be generated at a small site such as the Sasolburg manufacturing facility. A grand total of almost 10MWh was not anticipated. Investing in all the possibilities will unfortunately be very expensive and this means that Safripol will have to bear the risks involved, when moving its focus from being a polymer producer towards investing in power generation.

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