Department of Minerals and Energy Pretoria

# Capacity Building in Energy Efficiency and Renewable Energy

Report No. – 2.3.4 - 37

**Landfill Gas Resources for Power Generation in South Africa**

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November 2004

Department of Minerals and Energy Pretoria

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## Definitions, Abbreviations and Acronyms

***Clean Development Mechanism (CDM)*** – the CDM is specifically defined to support sustainable development with respect to greenhouse gas emissions in developing countries while helping Annex 1 countries to comply with their commitments under the Kyoto Protocol.

***CFC*** – chlorofluorohydrocarbons

***Environmental sustainability*** **–** the ability of an activity to continue indefinitely at current and projected levels, without depleting the social, cultural and natural resources required to meet present and future needs.

***Greenhouse Gases (GHGs)*** – gases primarily carbon dioxide, methane, and nitrous oxide in the earth's lower atmosphere that trap heat, thus causing an increase in the earth's temperature and leading towards the phenomenon of global warming.

***Grid*** **–** the generic term used to describe both the National Electricity Grid; being all electricity networks of licensed electricity distributors and transmitters within South Africa, and the Eskom transmission system.

***Renewable energy sources*** – sun, wind, biomass, water (hydro), waves, tides, ocean current, geothermal, and any other natural phenomena which are cyclical and non-depletable.

**Watt** (W) – 1 Joule **per second** of **energy** consumption or dissipation (MW = 1000 000 W)

***$Nm^3$*** **–** a standard measurement of gas volume defined as 1 cubic metre of the gas at zero degrees centigrade and 1013 milli Bar pressure.

**Electrical Units of measure**

Power
Megawatt (MW) – a unit of power (rate of energy consumption) defined as one Megawatt = 1 000 kilowatts or about 1 340 horsepower.

Energy
Kilowatt hour (kWh) – a unit of energy consumption defined as one kilowatt hour = 3.6 MJ (MegaJoules) or 3 412.14 Btu (British thermal units) or 859.855 kcals (kilocalories).

Mega Watt hour (MWh) – a unit of energy consumption defined as one Mega Watt hour being the amount of energy consumed in one hour at a rate of one Mega Watt.

Giga Watt hour (GWh) – a unit of energy consumption defined as one Giga Watt hour = 1 000 Mega Watt hours.

| | |
|---|---|
| LFG | Landfill Gas |
| DWAF | Department of Water Affairs and Forestry |
| SEGP | Standard Electricity Generating Plant |
| DSW | Durban Solid Waste |
| DMA | Durban Metropolitan Area |
| NER | National Electricity Regulator |
| NERL | New England Road Landfill |
| PMB | Pietermaritzburg |
| UNFCCC | United Nations Framework Convention on Climate Change |
| CER | Certified Emission Reduction |
| PLC | Programmed Logic Controller |

# 1 Executive Summary

South Africa is well endowed with renewable energy resources. However, less than 1% of the total electricity generated in South Africa is based on renewable energy. Renewable energy resources in South Africa include biomass, hydro, solar, wind and wave power. The theoretical potential for renewable energy corresponds to approximately 50% of the present national electricity production.

The South African Govervent has established an ambitious target for the role that renewable energy will play in the energy generation mix in South Africa. This target is documented in the White Paper on Renewable Energy which was approved by the Cabinet in November 2003. The target formulated in the White Paper:

*10 000 GWh renewable energy contribution to final energy consumption by 2013, to be produced mainly from biomass, solar and small-scale hydro. The renewable energy is to be utilised for power generation and non-electric technologies such as solar water heating and biofuels.*

This target corresponds to some 5% of the present total annual electricity generation. The draft strategy for renewable energy states that this target will be achieved by utilising a mix of different renewable energy resources and applications. The selection of renewable applications will be based on the least-cost principle. The 10 000 GWh target will be implemented in three phases during the 2004 – 2013 period. A study commissioned by the DME and CaBEERE entitled "Economic and Financial Calculations and Modelling for the Renewable Energy Strategy Formulation" highlighted landfill gas extraction for electricity generation as one of the low cost renewable energy options for meeting the White Paper Target. The current report helps to resource and build capacity in the DME and relevant stakeholders to formulate and facilitate implementation strategies and legislation to promote the economic use of renewable energy in rural and urban areas.

**Landfill gas is an Environmental Problem**

Landfill gas causes several problems, including odour propagation, vegetation die-back, explosive and asphyxiating conditions in enclosed spaces. Landfill gas migration is strongly influenced by falls in atmospheric pressure. The best method of controlling gas migration is active gas extraction with a pump and the flaring of the extracted gas. A detailed discussion of practical landfill gas management is presented in Appendix 1. Active landfill gas extraction/leachate pumping and flaring or utilisation from a landfill provides the following benefits:-

- Landfill gas migration control
- Odour control
- Increased rate of settlement resulting in additional air space for landfilling
- Increased rate of waste stabilisation

- Reduction in leachate migration
- Reduction in Greenhouse gas emissions
- Fossil Fuel Energy Replacement

**Development of Site Selection Protocol**
A site selection protocol based on the landfill classification system developed in the *Minimum Requirements for Waste Disposal by Landfill Second Edition 1998*, as issued by the Department of Water Affairs & Forestry, was used to screen all the landfill sites in South Africa using size, quantity of waste that had been landfilled, type of waste (including an assessment of how readily biodegradable the waste was), the age of the site, whether it was operational or had been closed already, its planned closure date as well as the sites proximity to power lines and other potential users. The *Minimum Requirements for Waste Disposal by Landfill Second Edition 1998* are obtainable in CD format from the Department of Water Affairs & Forestry. The above mentioned criteria were used to develop the questionnaire which was used to collect the data for the study. The questionnaire is presented in Section 3.2 below.

**Data Collection**
The data capture proved extremely time-consuming. Consequently most of the study time was spent on personally collecting and verifying data. It was apparent that landfill owners/operators did not see the provision of data as a “core business” and responses were frequently slow or not forthcoming at all. Most local authorities did not maintain easily accessible waste data records. A considerable effort was required from the team members to obtain the required information via personal visits and repeated telephone follow-up calls. The collected data has been archived by the CaBEERE Project at the DME in Pretoria.

**Mapping of Potential Landfill Gas Utilisation Project Sites**
A survey carried out in terms of this brief during the period June to October 2004 established that 453 sites were operational or in the process of being permitted. The site selection process led to the evaluation of 57 Sites throughout South Africa which were analysed to determine the potential power that could be produced through the extraction of landfill gas. The landfill sites were mapped using a simple GIS which employed layers that included the site names, size, tonnage input of solid wastes and the potential landfill gas that may be extracted for each site. South Africa has a substantial probable energy resource from landfill gas within the major conurbations. The maps are presented in Appendix 2.

**Quantification of Landfill Gas Yields**
The main findings and conclusions of the study of disposal sites indicate that there were numerous small landfills, but the majority of the airspace was associated with the larger landfills located in the metropolitan municipal areas. Landfill regionalisation was occurring on a significant scale, particularly in the urbanised areas and this trend should be encouraged both for environmental control and the potential for energy recovery. The possible methane production was modelled using a European Union modification of the Tabarasan Model.

**Assessment of Lifespan of Projects and Probable Electrical Yield Available**
The sites that have emerged as feasible in terms of this study are estimated to be capable of almost matching the RE target set for 2013. The power generation estimates provided are conservative and can be expected to grow as the volume of waste landfilled in operating sites increases. The available GWh have been calculated on the basis of a conservative 90% plant availability which, together with the conservative approach that has

been adopted throughout this study suggests that it not unlikely that the energy yields might be expanded by as much as 20%. The spreadsheets used in the calculations are filed in Appendix 3.

The top twenty sites have been tabulated below in descending order of power generation potential relative to the year 2008.

***Table 1: Top 20 National Landfill Sites for Power Generation using Landfill Gas***

| Probable Power MW e | Province | Year | | |
|---|---|---|---|---|
| **Landfill** | | **2005** | **2008** | **2012** |
| **Linbro Park CoJ** | **G** | 3 | 7 | 4.5 |
| **Vissershok CMC** | **WC** | 3 | 6 | 5 |
| **Valhalla Tshwane** | **G** | 5 | 4 | 2.5 |
| **Bisasar Road** | **KZN** | 4 | 4 | 8 |
| **Marie Louise CoJ** | **G** | 3 | 4 | 5 |
| **Robinson Deep CoJ** | **G** | 3 | 4 | 5 |
| **Deerdepoort Tshwane** | **G** | 1 | 3.5 | 2.5 |
| **Rooikraal EMM** | **G** | 2 | 3 | 4 |
| **Bellville South** | **WC** | 2 | 3 | 2 |
| **Kwaggasrand Tshwane** | **G** | 2 | 3 | 6 |
| **Onderstepoort Tshwane** | **G** | 2 | 3 | 4 |
| **Goudkoppies CoJ** | **G** | 2 | 3 | 4 |
| **Weltevreden EMM** | **G** | 1.5 | 2 | 3 |
| **Garstkloof Tshwane** | **G** | 1.5 | 2 | 3.5 |
| **Coastal Park** | **WC** | 1 | 2 | 2 |
| **Koedoeskloof** | **EC** | 1 | 2 | 3 |
| **Simmer & Jack EMM** | **G** | 1 | 2 | 3 |
| **Boitshepi Emfuleni** | **G** | 1 | 2 | 3 |
| **Southern Bloem** | **FS** | 1 | 2 | 2 |
| **Ga-Rankuwa Tshwane** | **G** | 1 | 2 | 2 |
| **Total MW e** | | 41 | 63.5 | 74 |
| **Grand Total MW e** | | **62.5** | **91.6** | **105.4** |
| **GW h** | | **323** | **501** | **583** |
| **Percent of Total** | | **65.6%** | **69.3%** | **70.2%** |

This resource must be utilised as part of the national energy mix. Although 57 landfill sites have potential relative to the conversion of landfill gas to electrical energy it can be clearly seen from Table 1 above that the 20 best opportunities yield close to 70% of the probable energy which will make a considerable contribution to the total potential feasible landfill gas to electrical energy potential by 2012.

## Feasibility Checklist

Landfill operators must be encouraged to maintain up to date, accurate and easily accessible records that meet the requirements of the Project Feasibility Checklist provided in Chapter 6 that has been designed to assist landfill operators with the assessment of the viability of their operations with respect to power generation. This Project Feasibility Checklist was developed by the CaBEERE Project Team to assist Independent Power Producers with the development of renewable energy projects that use landfill gas.

**The Bisasar Road Landfill Case Study**

A case study has been shared with the reader both in the form of précis in Chapter 5 of the report and as Appendix 4. The case study deals with the Ethekwini Metropolitan Council's landfill gas to electrical energy project which largely corroborates the findings of this study.

# 2 Introduction

The Department of Minerals and Energy (DME) in South Africa is responsible for formulating strategies and drafting legislation for the South African energy sector. The Directorate for Renewable Energy in the DME finalised the White Paper on Renewable Energy which has been approved by The Cabinet in November 2003. Hereafter the strategy and subsequent detailed action plans will follow as a direct result and further detailing of the RE White Paper. The RE target of 10 000 GWh renewable energy contribution to final energy consumption by 2013 will be produced mainly from biomass, wind, solar and small-scale hydro-electrical energy sources. Renewable energy is to be utilised for power generation and non-electric technologies such as solar water heating and bio-fuels. There is no one correct mix of these technologies, but the aim of the Government is to optimise the mix in such a way that the technologies introduced are those, which makes best macro economic sense, while at the same time supports the achievements of the goals of the White Paper on Renewable Energy.

As a result of a dialogue between the DME and Danida over the years 1999 to 2001 the Project "Capacity Building in Energy Efficiency and Renewable Energy" (CaBEERE) was formulated. The Project aims to enhance the DME's capacity and performance by assisting in developing programmable approaches through strategies and actions plans for energy efficiency and renewable energy in transparent co-operation with all the relevant stakeholders. The Project approach is primarily built on learning by doing; through on the job training of DME staff and other stakeholders. At the end of the project the DME will be able to effectively and efficiently meet its energy efficiency and renewable energy mandate as prescribed by the energy policy and be in a position to sustain this capacity.

The World Bank in collaboration with the Government of RSA, in particular the DME and the NER, has prepared a World Bank/DME project proposal for investments in Renewable Energy Technologies (RE) to replace 4,000 GWh of coal-fired power generation. In order to prepare for the introduction of this programme and ensure that such a programme contributes to the achievement of the RE target specific capacity building needs to be carried out by the DME.

This study aims to assist in building capacity in the technical and environmental evaluation of landfill gas for power generation in South Africa. The project is informed by the international emphasis that currently focuses on landfill gas, particularly in terms of the Cleaner Development Mechanism (CDM) potential related to the Kyoto Protocol. More recently, the Renewable Energy Market Transformation (REMT) Project completed by Conningarth Economists helped to increase the focus on active landfill gas management systems and the down stream use of extracted landfill gas for power generation, direct combustion as a heat source and gas quality upgrade for vehicle or natural gas supplementation in South Africa.

A specialised team of knowledgeable, experienced waste scientists and engineers was assembled by the Consultant. These sub-consultants had contacts in the specific provinces where they elected to collect data. The project was undertaken by Lombard & Associates from Ethekwini Metro South Africa under the management of COWI who is the main contractor in the CaBEERE Project. Team members consisted of the following:

H. Rask-Grøn, COWI - Team leader
R. Lombard and GWP de Mattos, Lombard de Mattos & Associates – Principal Sub-Consultant
J B Otto, Kobus Otto & Associates
T Kristiansen and J Møller, RAMBOLL
A Naude, Annette Naudé Associates

The project was managed by the DME Landfill Resources Task Team Meetings which comprised:

A Otto, DME
S Tshaka, DME
K Naidoo, CaBEERE
L Visagie, CaBEERE Admininstration
J Shabalala and S Ngubane, Central Energy Fund
R Lombard, Lombard de Mattos & Associates

## 2.1 Landfill Gas

In South Africa, landfilling is currently the more viable option for the disposal of South Africa's growing solid waste, despite this method representing the lowest level on the waste management hierarchy. Waste minimisation, re-use and recycling will help to reduce the volume of waste delivered to sites in the future, however, landfilling will still play an important function of waste management in the foreseeable future. Sanitary landfill operations, involve the controlled spreading, compaction and covering of refuse with earth which rapidly establishes anaerobic conditions. The continuous generation of biogas results in the build up of landfill gas pressure in the site. The pressure created forces the migration of gas to the surface and perimeters of the site and reduces the generation rate due to feedback inhibition of the methanogenic bacteria.

Landfill gas is a general term used to describe the gaseous components produced during microbial degradation of organic waste in a landfill site. Biodegradable organic wastes include animal and vegetable waste matter, paper, wood, garden refuse and putrescible materials found in urban solid waste that decay rapidly.

The major constituents of landfill gas are methane and carbon dioxide. These gases are colourless and odourless but are normally found mixed with small quantities of other gases which can give rise to odours. Typical malodorous compounds are hydrogen sulphide ($H_2S$), esters, terpenes, mercaptans and volatile fatty acids.

Landfill gas has the following characteristics and impacts:-

- Saturated with moisture: up to 4 % by mass, depending on the temperature, e.g.at 25ºC landfill gas typically has 1.8 % moisture content by mass

- Corrosive: metal pipes and fittings corrode in the presence of landfill gas
- Explosive: the explosion limits of methane are 5 and 15 % by volume in air in the presence of at least 14 % by volume oxygen
- Flammable: landfill gas is a good alternative source of renewable energy if generated in sufficient quantities.
- Toxic: carbon dioxide at higher concentrations is toxic to living cells
- Asphyxiating: landfill gas accumulates in enclosed spaces, excluding oxygen, thus posing a health hazard.
- Phyto-toxic: landfill gas can cause vegetation die-back by displacement of oxygen and an increase in temperature, and therefore desiccation, in the root zones of plants.
- Global warming potential: Methane and carbon dioxide are both greenhouse gases that can absorb infra-red radiation from the earth's surface, normally lost to space, and re-radiate some of it back to earth as heat. The global warming potential of methane is 21 times that of carbon dioxide.

It is important to understand how the gas is generated (source), how it migrates (pathway), and consequently how to assess and monitor sites so that the risk to humans and the environment (receptors) associated with landfill gas accumulation and/or migration can be effectively managed. Further, if landfill gas is to be utilised as an energy source it must also be monitored in order to predict collectable gas yields and the potential for energy recovery.

### 2.1.1 Landfill Gas Generation

All landfill sites that contain waste materials that can be broken down by micro-organisms will produce landfill gas. The greater the amount of biodegradable organic material in a landfill site, the greater its potential to generate landfill gas. There are many factors which influence landfill gas production including:-

- types of waste
- size and depth of the waste body
- moisture content
- landfill pH
- temperature
- waste density.

Waste decomposition goes through a number of stages from aerobic to anaerobic, which result in the generation of methane gas in the final stage. The production of significant quantities of methane may take from 3 months to more than a year to start and can continue for well in excess of 15 years after the landfill site closes.

### 2.1.2 Landfill Gas Migration

Four incidents involving landfill gas explosions have been recorded in KwaZulu-Natal. In one case two deaths resulted and a third worker was badly burned as a result of a landfill gas explosion that took place ion the New England Road Landfill that serves the Pietermaritzburg/Msundusi Local Municipality. In the United Kingdom landfill gas has been shown to move up to 2 km from its source. Several factors that influence the movement of landfill gas must be taken into account when planning to monitor or manage landfill gas.

Landfill gas may move in any direction within the waste body iteslf:-
- Laterally along more permeable layers and associated with leachate flow
- Vertically under dry weather conditions.
- Vertically at the side of the site escaping via settlement cracks.

Landfill gas can move beyond the landfill site itself, thus posing an off-site health and safety risk:-
- Through permeable strata or for considerable distances along faults, fissures or cavities in the strata.
- Along man made features such as mine shafts, roadways, sewers, service lines, pipes etc.
- Dissolved in leachate and water and subsequently released at some distance from the site boundary.

Migration pathways are affected by:-
- Changes in the permeability of the waste as it settles and decomposes or by subsequent disturbance of the site.
- Changes in atmospheric pressure
- Soil moisture and soil chemistry.

## 2.2 Technology Description

Landfill gas control elements are containment, collection and/or treatment. Where monitoring indicates that off-site threshold values for methane are being exceeded it may be necessary to allow for control measures that prevent uncontrolled migration or emission of landfill gas, as agreed with the Department of Environmental Affairs and Tourism and the Department of Water Affairs & Forestry.

It must be emphasised that the primary function of the LFG management system is to ensure safety. Safety must not be compromised in the interests of thermal energy usage. If landfill gas is not managed correctly it impacts negatively on the receiving environment. LFG technology provides for the safe management and destruction of landfill gas whilst meeting strict environmental emission standards.

Various options exist for the use of landfill gas:
- As thermal energy for processes in industry, e.g. kilns, furnaces, driers or raising steam.
- For the generation of electricity.
- In South Africa, landfill gas has been used as a raw material chemical feed stock for the commercial production of cyanide.

### 2.2.1 Passive Management of Landfill Gas

This approach relies on good management backed by the following civil engineering interventions:-

### Gas Barriers

Clay or bentonite linings, synthetic members or grout curtains have been used as a barrier to restrict the migration of leachates from landfills. Reworked clay and certain bentonite linings are probably the most commonly available natural materials for gas barriers. They should be laid and compacted to achieve a coefficient of permeability equal to or better than 1 x $10^{-9}$ m/s. Ideally synthetic membranes should be flexible, durable, of very low gas permeability and exhibit high resistant to tearing or puncturing. Barriers can be used around closed sites, but their application is limited by the depth of trench that can be dug and the fact that no barrier can be installed across the base of the site. For shallow sites with depths to about 5 metres a synthetic membrane can be laid in a trench to provide a barrier. They can be installed in 0.5 metres wide trenches, which should be dug to a depth greater than the maximum site depth. A slurry trench can be used for depths greater than 5 metres or in difficult ground. A slurry is usually composed of bentonite and concrete. The bentonite is hydrated and blended with concrete prior to being fed into the trench. The trench, usually at least 0.6 metres wide, is filled with the slurry as excavation proceeds, such that the slurry supports the sides of the trench. The mixture is self-setting with a consistency of stiff clay and a coefficient of permeability to water better than 1 x $10^{-9}$ metres/sec. Slurry trenches can be dug to depths of 30 metres with specialised equipment. A method of improving the effectiveness of a slurry trench is by the addition of an HDPE (High Density Polyethylene) or other synthetic sheet within the slurry. Grout curtains have also been used to act as a gas barrier. There are usually constructed by drilling boreholes close together in a staggered pattern along a line. The interval between boreholes is dependent on the type of strata, though 1 metre centres is typical.

### Permeable Trenches

Vent trenches, about 1 metre wide, filled with “no fines” crushed aggregate of uniform size can provide a route through which gas can vent. The side of the trench furthest from the landfilled waste should be sealed with a low-permeability barrier of natural or synthetic material and the rest of the trench lines with a fabric filter to prevent blinding of the medium. Perforated or slotted pipes of suitable strength material (such as class 3 HDPE, medium density polyethylene (MDPE), polypropylene or uPVC) should be installed in the trench and connected to surface vent pipes of similar construction. Such pipes should be at least 100mm in diameter.

There are several difficulties in using permeable trenches, such as wind-blown waste or fines blocking trenches and reducing gas flow, landfill gas is emitted constantly as it vents to the atmosphere and can create odour problems and become a nuisance to local residents.

## 2.2.2 Active Management of Landfill Gas

Active landfill gas extraction schemes consist of landfill gas extraction wells connected through landfill gas recovery pipelines to a pump and flare station. Monitoring of the soil atmosphere in gas probes established in the soil around any landfill site may indicate the need for an active landfill gas extraction scheme.

Historical survey data is used to produce a digital terrain model (DTM) of the landfill site reflecting the original topography of the site, the current land form and the final geometric design of the site. DTM is used to position exploratory wells and, later, the gas curtain extraction and production wells for the landfill gas extraction scheme. A pumping trial may be carried out over several months in order to establish a steady state in the landfill gas yield. Initially, residual biogas that has built up within the landfill must be extracted and microbial catabolism stimulated to produce the sustainable gas yield that the gas pumping trial is designed to measure. Once the yields of individual gas wells have been stabilised the following measurements are carried out at regular intervals:-

- Gas velocity
- Volumetric flow rate
- External temperature
- Barometric pressure
- %$CH_4$

**Benefits of Active Landfill Gas Extraction Systems**

*Migration Control* - Gas extraction is the only effective method of controlling migration from a landfill site. This is achieved by the use of a specifically designed gas well curtain in order to prevent migration to specific high-risk areas. The gas wells for environmental control involve the creation of a gas control curtain on the periphery of the landfill site which requires the location of gas wells at smaller centres than for gas production wells. Curtain wells will produce gas with lower $CH_4$ and higher $O_2$ concentrations in order to prevent gas escaping. Such gas must usually be flared separately in order to obviate gas quality problems with potential downstream users of the landfill gas. In some circumstances special 'pump and disperse' systems may be required where gas is of too low a quality to be flared safely. These systems have additional safety measures installed to allow them to pump potentially explosive mixtures.

*Odour Control* - This is a major problem for landfill managers, and the normal odour associated with fresh waste can only be controlled by rapid compaction and cover. The general odour released by landfills is not produced by $CH_4$ and $CO_2$, but by traces of reduced sulphur compounds, volatile fatty acids and volatile amines. Since landfill gas is the carrier of these compounds and the mechanism of their dispersal, the only effective management is to actively extract and flare or use of the gas as a thermal energy source.

*Physical Settlement* - Landfill settlement has two major components, the first being immediate or physical settlement due to the mass loading that each new layer of waste imposes when placed on top of the older layers. The second is long term or creep settlement related to biodegradation associated mass transfer processes in the landfilled waste. Differential settlement creates problems of its own and constrains the after-use options related to rehabilitated landfill sites. The impact of the mass transfer phenomenon can be quite profound, e.g. an average of 2 m settlement has been recorded on a 30 m deep terrace of a landfill. This settlement is attributed to the collapse of the waste fill into the voids that have been created in landfilled waste through the extraction of landfill gas, condensate and leachate. Waste is not a homogeneous mixture consequently the settlement is not uniform.

*Biological Stability* - The amount of gas produced by each landfill is finite and related to the nature of the waste disposed of in the site. If unmanaged, landfill gas will disperse naturally over a 30 – 50 year period. However, this time frame will reduce to approximately 10 – 15 years if the landfill gas is actively extracted in the case of a closed site. In both cases the waste mass can be considered biologically stable once the finite gas volume has been generated.

*Leachate Extraction* - Waste in a landfill is separated by a network of structural voids, or macropores, and this is where liquid flow occurs. Waste compaction increases as additional layers of refuse are built up and microbial degradation occurs. Compaction increases with depth and permeability decreases therefore the idea of a continuous leachate piezometric level in landfill waste is not valid. It is usually necessary to remove leachate from gas wells where water surplus conditions exist in order to ensure efficient gas removal. With the variation in leachate levels, wells normally fill from the many perched leachate horizons which they intersect within the waste mass. It has been shown that leachate level control is best performed in gas wells that are combined with leachate extraction systems rather than in separate wells due to the complex flow regimes that are experienced in landfill sites. Pumping leachate from a landfill reduces the potential for leachate to reach the receiving environment and removes waste breakdown products which further hastens waste mass stabilisation. The pumped leachate may require pre-treatment prior to disposal to a normal sewer connected to a waste water treatment works. Water surplus conditions may exist due to a positive climatic water balance or the co-disposal of liquids in the landfill site.

*Global* Benefits - Both $CH_4$ and $CO_2$ contribute to the “greenhouse” effect. $CH_4$ is 21 times more efficient in radiating energy back to earth than $CO_2$. Trace components of CFC's can be found in landfill gas due to the disposal of aerosol cans, CFC blown styrene foams, refrigerator and air conditioner leaks. Collection and combustion of landfill gas converts the $CH_4$ to $CO_2$ and water. The contribution of landfill gas to the greenhouse effect is thereby reduced. CFC's are destroyed in flares with the destruction efficiency dependant on flare temperature and design. Municipal solid waste contains almost 30% biodegradable carbon of which two thirds may be converted to landfill gas. If the gas is not collected and flared there is a very substantial contribution to the greenhouse effect from the $CH_4$ component. There is a further reduction in greenhouse gas generation if the energy value of $CH_4$ replaces fossil fuel use. High efficiency gas collection and energy recovery schemes are essential in reducing $CH_4$ emissions.

### 2.2.3 Utilisation of Gas from Landfill Sites

In South Africa, the relatively low cost of energy production is a serious constraint on the viability of most of the above uses of landfill gases that were mentioned and the primary economic benefit of landfill gas extraction, whether by flaring the gas or recovering it for use, lies in extending the life of landfill sites. This occurs through the accelerated settlement of the landfill as a result of optimising the catabolism of the biodegradable fraction of the waste which conserves airspace. However, the continual increase in the price of petroleum and the high green house gas emissions, LFG utilisation for energy production may represent an important alternative energy source for economically developing countries. It is therefore fundamental to develop and implement LFG recovery technologies that involve low investment, operational and maintenance costs, are relatively labour intensive with low energy consumption in order to yield a highly positive energy balance.

Emissions from landfill gas combustion are able to comply with the most stringent European Standards provided correct flare technology or ignition control in spark ignition engines is selected, however meeting these strict criteria is more costly.

#### Direct Gas Use

The option for medium heating value landfill gas (5KWh/Nm$^3$ at 50% $CH_4$) include use as boiler fuel, space heating and cooling, and industrial heating/co-firing applications. The use of LFG as a fuel for boilers to raise steam is a relatively popular option in developed countries as conventional equipment can be used with relatively little modification and boilers are less sensitive to the trace constituents of LFG. Consequently less gas clean up is required compared to other methods of LFG use. However, a limitation of this option is that a LFG customer must be in close proximity, preferably within a 2-3 km radius and the direct thermal use of

LFG requires an additional energy input of 3 – 4% to compensate for the energy lost in heating the non-combustible $CO_2$ component.

Other options for medium heating value gas include industrial applications such as lumber drying, kiln operations, and cement manufacturing. The advantage of many industrial applications is that fuel is required continuously. LFG can also be used as a supplement to meet a portion of the total demand. The direct use of landfill gas in applications such as cement kilns, asphalt hot mix plants, brick kilns, glass furnaces, incinerators or steam raising may be the more economic option in the South African context. South Africa's current electrical energy pricing structure does not cover the cost of generating electrical power using landfill gas.

**Electricity Generation**

Most LFG recovery projects that generate electricity use internal combustion (IC) or gas turbine engines. The type of equipment is generally determined by the volume of gas available and the air pollution requirements:-

*Internal Combustion Engines* - Reciprocating IC engines drive electrical generators to produce electrical power, which can be sold to the local electric utility. The engines ideally should be designed specifically for LFG applications. The Reciprocating engines used for LFG applications range from stoichiometric combustion to leaner combustion engines. The 'lean-burn' engines are a turbocharged design that burn fuel with excess air. The stoichiometric or 'naturally aspirated' engines are stoichiometrically carburetted with just sufficient air in the fuel-air mix to burn the fuel. These machines average 35 to 40% energy utilisation efficiency.

*Gas Turbines* - Gas-fired turbines take large amounts of air from the atmosphere, compress it, burn fuel to heat it, then expand it in the power turbine to develop shaft power. The power generated can be used to drive pumps, compressors, or electrical generators (McGee & Esbeck, 1988). In projects utilising gas turbines it has been shown that they have a typical energy utilisation efficiency of 28 to 32% and turndown performance is poor in comparison with that of internal combustion engines. Turbines perform best when operated at full load and difficulties occur when they are operated at less than full load. A benefit reported from the use of turbines is that less day to day maintenance is required compared with the use of lean-burn engines.

*Fuel Cells* - In a fuel cell, hydrogen from LFG is combined electrochemically with oxygen from the air to produce direct current electricity and by-product water. The fuel cell is designed for automatic, unattended operation, and can be remotely monitored. Fuel cells are a popular option for LFG due to the higher energy efficiency, availablity to smaller as well as larger landfills, and recorded minimal by-product emissions. Other advantages include minimal labour and maintenance costs, as well as low noise impacts. Given the higher energy efficiency and potential for minimal by-product emissions, fuel cells may be the only alternative for areas where there are stringent requirements for NOx and CO emissions.

The utilisation of LFG is sensible in terms of economics, the environment and energy usage. The utilisation of alternative energy sources such as LFG extends global fossil fuel resources. Not only are emissions directly reduced when LFG is collected and recovered for utilisation, but emissions are indirectly reduced when secondary air-emissions impacts associated with fossil fuel use are considered.

# 3 Methodology

## 3.1 Data collection

The collection of reliable, relevant and relatively accurate data was critically important to the success of this project. Hence, the consultant focussed on techniques that ensured that the most accurate possible data would be collected within the time frames and budget constraints set by the project. The consultants used the approach set out below to ensure data integrity.

A preliminary screening process to eliminate the number of landfills that required detailed consideration in terms of the landfill gas production potential was developed. An appropriate method was agreed with the client to eliminate communal, small and the smaller medium sized landfill sites as well as certain types of mono-fills that are not relevant in terms of landfill gas generation.

A simple questionnaire was designed to facilitate easy completion by the landfill operators. These questionnaires were completed either during personal visits to or dedicated telephone interviews with the relevant representative/s of the local authority or private operation.

A number of verification tests were reemployed to validate the data collected, including comparison of data captured from the following principle sources:-

- reports by operators, e.g. based on weighbridge records, number and size of trucks entering the site, etc;
- estimates based on the landfill footprint, depth and height of the landfill body;
- estimates based on unit generation rates and the estimated number of inhabitants living in the areas the landfill is servicing and,
- records in permit applications and the Department of Water Affairs & Forestry landfill information records.

## 3.2 Survey questionnaire

A survey questionnaire was produced to facilitate with data collection. This is illustrated below:-

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| | | | | | | |
|---|---|---|---|---|---|---|
| LANDFILL DETAILS: | **LANDFILL NAME:** | | **LANDFILL OWNER:** | | **DATE OF SURVEY:** | |
| PHYSICAL ADDRESS: | **STREET:** | | **SUBURB:** | | **TOWN / CITY:** | |
| GPS COORDINATES: | **LATITUDE-X:** | | **LONGITUDE-Y:** | | **ALTITUDE ABOVE MEAN SEA LEVEL:** | |
| RESPONSIBLE PERSON | **NAME:** | | **POSITION HELD:** | | **CONTACT NUMBER:** | |
| LANDFILL PERMIT: | **CLASSIFICATION (MIN. REQUIREMENTS):** | 1.1.1.1 | **PERMITTED (YES / NO / IN PROCESS):** | 1.1.1.2 | **YEAR PERMITTED (IF APPLICABLE)** | |
| AVERAGE MONTHLY WASTE DISPOSAL: | **EXCLUDING DAILY COVER (TON/MONTH)** | | **INCLUDING DAILY COVER (TON/MONTH)** | | **AIRSPACE CONSUMED ($M^3$/MONTH)** | |
| ANNUAL WASTE DISPOSAL: | **EXCLUDING DAILY COVER (TON/YEAR)** | | **INCLUDING DAILY COVER (TON/YEAR)** | | **AIRSPACE CONSUMED ($m^3$/YEAR)** | |
| SITE LIFE | **YEAR COMMISSIONED:** | | **EXPECTED YEAR FOR CLOSURE:** | | **EXTENSIONS PROPOSED (YEARS ADDED):** | |
| AIRSPACE UTILISATION: | **AIRSPACE UTILISED TO DATE ($m^3$):** | | **AIRSPACE UTILISED BY LANDFILL CLOSURE ($m^3$):** | | **AIRSPACE REMAINING ($m^3$)** | |
| AVERAGE WASTE BODY THICKNESS: | **AVER. DEPTH BELOW GROUND LEVEL (m):** | | **AVER. HEIGHT ABOVE GROUND LEVEL (m):** | | **AVERAGE WASTE BODY THICKNESS (m):** | |

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| | | | | | | |
|---|---|---|---|---|---|---|
| | **DISPOSAL BELOW GROUND LEVEL (%):** | | **DISPOSAL ABOVE GROUND LEVEL (%)** | | **VALLEY DISPOSAL (%)** | |
| POSSIBLE GAS USERS (UP TO 5 KM): | **NAME OF INDUSTRY (1):** | | **TYPE OF INDUSTRY:** | | **DISTANCE FROM LANDFILL:** | |
| | **NAME OF INDUSTRY (2):** | | **TYPE OF INDUSTRY:** | | **DISTANCE FROM LANDFILL:** | |
| | **NAME OF INDUSTRY (3):** | | **TYPE OF INDUSTRY:** | | **DISTANCE FROM LANDFILL:** | |
| AREA OF LANDFILL FOOTPRINT: | **FOOTPRINT TO DATE ($m^2$):** | | **FINAL FOOTPRINT (HA):** | | **PROPOSED EXTENSIONS ($m^2$):** | |
| SURFACE AREA ON TOP OF WASTE BODY: | **AVAILABLE AT PRESENT ($m^2$):** | | **AVAILABLE AT CLOSURE ($M^2$):** | | **PROPOSED EXTENSIONS ($m^2$):** | |
| GENERAL INFORMATION: | **AVERAGE ANNUAL RAINFALL (mm):** | | **DISTANCE TO 11-KV POWER LINE (km):** | | | |
| SOURCE OF INFORMATION: | **PERSON NAME:** | | **POSITION HELD:** | | **CONTACT NUMBER:** | |
| | **REPORT TITLE:** | | **COMPANY/AUTHOR:** | | **REFERENCE NUMBER:** | |

| Constituents | % CONSTITUENT OF TOTAL | BIODEGRADABLE PORTION |
|---|---|---|
| **DOMESTIC WASTE** | | |
| **WET INDUSTRIAL (SLUDGES)** | | |
| **CONSTRUCTION RUBBLE** | | |

| Constituents | % CONSTITUENT OF TOTAL | BIODEGRADABLE PORTION |
|---|---|---|
| **GARDEN WASTE** | | |
| **DRY INDUSTRIAL** | | |
| **DAILY COVER** | | |

| YEAR | WASTE TONS PER ANNUM | ESTIMATED / MEASURED |
|---|---|---|
| **1984** | | |
| **1985** | | |
| **1986** | | |
| **1987** | | |
| **1988** | | |
| **1989** | | |
| **1990** | | |
| **1991** | | |
| **1992** | | |
| **1993** | | |

| YEAR | WASTE TONS PER ANNUM | ESTIMATED / MEASURED |
|---|---|---|
| **1994** | | |
| **1995** | | |
| **1996** | | |
| **1997** | | |
| **1998** | | |
| **1999** | | |
| **2000** | | |
| **2001** | | |
| **2002** | | |
| **2003** | | |

## 3.3 Waste data

The Department of Water Affairs and Forestry (DWAF) developed a database of landfills in the late 1990's. This database was outdated and did not record, in every case, all the variables required for the study, e.g. waste input rate, waste demography and balance of remaining site life. This database provided a list of sites in the various provinces and some indication of size but could not be used as an accurate source of input data. Furthermore the DWAF Minimum Requirements site size classification is based on daily input rate and not site area. As a result the DWAF site size classification was not ideally suited to the current task.

The quantity and type of waste landfilled in any disposal site as well as the size and depth of the landfill are required to model gas generation. The anticipated water balance of the site is also an important input used to decide whether or not the waste moisture content will limit gas production. For this study historical data going back 15 years was collected where available and waste inputs were projected for the next 20 years wherever the site's operating life was expected to extend that far into the future. Any available survey data of “in-place” waste volumes and the balance of site life was collected wherever available. A questionnaire was developed for completion by site owners and operators in conjunction with experienced members of the sub-consultant's team. It was clear that merely sending out questionnaires and verifying a sample of the returns would not have provided the required information either in terms of the number of replies nor the adequacy of information. Verification was based on 100% of all site data available.

## 3.4 Identification of Landfill Sites

In 1997, the Department of Water Affairs and Forestry and Department of Environmental Affairs and Tourism, with the financial assistance from the Danish Co-operation for Environment and Development (DANCED), commissioned a series of baseline studies to provide a better understanding of waste management in South Africa. These studies served as guidance for the development of a National Waste Management Strategy (NWMS) for South Africa.

The Municipalities of RSA Database for June 2004 was obtained from the Department of Provincial and Local Government, together with the municipalities old and new name listings, in order to ensure that all municipalities in each of the nine provinces were included in the survey.

For this study the estimated power generation was derived using the following assumptions:-

- Only landfills with a general waste input greater than 30 000 tonnes per annum were selected. These sites fall within the upper end of the medium sized general waste landfill sites, i.e. $GMB^+$ and $GMB^-$ sites and the large general waste landfill sites, i.e. the $GLB^+$ and $GLB^-$ in terms of the *Minimum Requirements for Waste Disposal by Landfill Second Edition 1998* as issued by the Department of Water Affairs & Forestry.
- The content of putrescible waste varied from 30 to 80% which is fairly typical.
- Only 70% of the gas generation predicted was used as the quantity that could be collected from a working site. On closure the quantity collected can rise to 80% or more.
- Closed sites were not considered due to the total lack of information available from the DWAF database. These sites could generate an additional quantity of gas and power estimated at >15%.

Landfill sites are classified in accordance with the *Minimum Requirements for Waste Disposal by Landfill Monitoring Second Edition 1998* as issued by the Department of Water Affairs & Forestry as depicted in the table below:-

| **LEGEND**<br>$B^-$ = No significant leachate produced<br>$B^+$= Significant leachate produced<br>R = Requirement<br>N = Not a requirement<br>F = Flag: Special consideration to be given by expert or Departmental representative | **CLASSIFICATION SYSTEM** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **G**<br>**General Waste** | | | | | | | | **H**<br>**Hazardous Waste** | |
| | **C**<br>**Communal Landfill** | | **S**<br>**Small Landfill** | | **M**<br>**Medium Landfill** | | **L**<br>**Large Landfill** | | **H:h**<br>**Hazard Rating 3 & 4** | **H:H**<br>**Hazard Rating 1 - 4** |
| **MINIMUM REQUIREMENTS** | $B^-$ | $B^+$ | $B^-$ | $B^+$ | $B^-$ | $B^+$ | $B^-$ | $B^+$ | | |
| **Landfill Gas Monitoring Plan** | F | F | F | R | R | R | R | R | R | R |

The first letter, i.e. G or H, denotes the class of waste deposited in the landfill and G = general waste and H = Hazardous Waste. The second letter denotes the size of the landfill, i.e. L = Large, M = Medium, S = Small, and C = Communal. The third letter denotes the Climatic Water Balance of the site, i.e. $B^-$ = a drier site, and $B^+$ = a wetter site. For more details kindly refer to *Document 2 of the Waste Management Series, Minimum Requirements for Waste Disposal Hazardous Waste Management and Monitoring Second Edition 1998* as issued by the Department of Water Affairs & Forestry.

## 3.5 Field Surveys

The data capture proved extremely time-consuming and so most of the study time was spent on collecting and verifying data. Landfill owners/operators did not see the provision of data as “core business” and responses were frequently slow or not forthcoming at all. Most local authorities did not maintain easily accessible waste data records. A considerable effort was required from the team members to obtain the required information via personal visits and repeated telephone follow-up calls. The DWAF site size classification was not ideally suited for this report and therefore could not be utilised.

GIS Mapping was undertaken to map the various sites. This was beneficial in illustrating the site names, size, tonnage input of solid waste and potential landfill gas extraction projected by site.

## 3.6 Site Visits and Permit Holders

Some site visits were necessary to verify data that were collected. The permit holders are accessible in the DWAF Permit Status Report for Class G sites dated 11 August 2004 and it was decided by the Project Steering Committee to limit the investigation to permitted facilities only.

## 3.7 Landfill Gas Models

According to Cossu, Andreottola and Muntoni (Modelling Landfill Gas Production – Centro di Ingegneria Sanitaria Ambientale, 1996) there is a pressing need for landfill gas models able either to forecast the yield and production rates of biogas generated, or to evaluate the potential gas migration and related problems. The development of landfill gas models started in the 1970s, when several authors summarised experimental data on a rational basis (Alpern, 1973; Boyle, 1976; Ham et al 1979). Qualitative models were developed by Farquhar and Rovers (1973). Quantitative models were later provided in the USA (Palos Verdes, Scholl Canyon, Sheldon Arleta and EMCON (USEPA) models). Depending on the approach, different classifications of models are possible. A general classification can be based on the availability of data and the state of knowledge of the system:

**Statistical analyses**
When a large array of data are available but knowledge of the system is inadequate, and the data are collected for different purposes; this kind of model does not assume any cause and effect relationship or deal with the temporal dynamics of the system, but presents the general characteristics of the data population and provides correlations.

**Stochastic model**
This describes the temporal trend of data without explaining the same; this type of model is useful for describing the behaviour of a “black-box” system as it states simply which ouput is related to which input.

**Simplified deterministic model**
This requires knowledge of the mechanisms governing the system and is able to describe the behaviour of the system with simplified mathematical equations.

**Complex deterministic model**
This acts in a similar way to the aforementioned model but employs much more complex mathematical equations.

The majority of the landfill gas models belong to the third category. Deterministic models are also divisible into static and dynamic models. Static models create an instantaneous relation between input and output; the state of the system is stationary and time has no influence. Dynamic models inputs and outputs are not instantaneous and variable that describe the temporal evolution of the system must be introduced. Cossu and Andreottola in 1988 also distinguish biogas generation models into some other classes such as empirical models, stoichiometric models, biochemical models and ecological models. Theoretically a complete biogas model should include three sub-models :-

**Stoichiometric sub-model**
This gives the maximum theoretical yield of biogas from the anaerobic degradation of of the organic waste fraction.

**Kinetic sub-model**
This is a dynamic model, which gives a result that reflects the impact of time on landfill gas generation rates. It can be an empirical model based on a simple equation of a defined order or a deterministic model, based on a set of equations describing the degradation of the different fractions of the biodegradable municipal solid waste; or an ecological model which describes the dynamics of the microbial populations and substrata within the landfill.

**Diffusion sub-model**
This is a dynamic model which describes the time and space variation of pressure and gas composition within the landfill body. Landfill gas emission rates can be obtained and the effectiveness of the gas extraction system can be verified.

Any model aiming to describe the processes in a landfill will always be affected by uncertainties due to the impossibility of controlling conditions in landfills. For this reason model output is best expressed in terms of probable ranges instead of absolute values. The choice of the order of the kinetics of the model appears not to be as significant as the selection of appropriate values for the decay rate constants and the quantification of the biodegradable waste substrate. Uncalibrated models should only be applied in the first planning stage of landfill gas exploitation programmes. In general, there is a paucity of good long term field data available in South Africa in order to calibrate models.

The waste data was used to model gas and energy yields using a similar model to the European Union modification of the Tabarasan model. In calculating the kW capacities of the sites modelled, a very conservative approach has been adopted. It is quite possible that these estimates may only be 50% of the true potential that could be available from these sites.

**Examples of gas yield calculation models**

*Simple initial estimate*
Where the site assessment indicates that landfill gas could be generated in more than negligible quantities, this will trigger the introduction of measures to control the escape of landfill gas off-site. The following model can be used in estimating methane generation from a landfill site that has accepted biodegradable wastes. It assumes that each tonne of biodegradable waste will generate 10 $m^3$ of methane per year and results in an overestimate of gas flow at peak production and gas flow from historic waste deposits.

**Figure 1: Initial simple estimate of gas generation**

$$Q = M \times 10 \times T / 8760$$

**Where:**
**Q = methane flow in $m^3/h$**
**M = annual quantity of biodegradable waste in tons**
**T = time in years**

**Reference:** Environment Agency/SEPA Sept 2004 Guidance on the management of landfill gas www.environment-agency.gov.uk/commondata/105385/

A predicted methane flow (Q) that exceeds a simplistic benchmarked value of 50 – 100 $m^3/h$ provides an initial indication that flaring or utilisation could be undertaken.

*First Order Kinetics Model to estimate gas generation*
Several complex models of gas generation can also be used for more accurate calculations of landfill gas generation. Figure 2 is a US EPA model, developed for the Mexico.

**Figure 2: First Order Kinetics Model for estimating gas generation in landfills**

$$Q_M = \sum_{i=1}^{n} 2\, k\, L_o\, M_i\, (e^{-kt}i)$$

$\sum_{i=1}^{n}$ = sum from opening year +1 (i=1) through year of projection (n)

$Q_M$ = maximum expected LFG generation flow rate ($m^3/yr$)

k = methane generation rate constant (1/yr)

$L_o$ = methane generation potential ($m^3/ton$)

$M_i$ = mass of solid waste disposal in the $i^{th}$ year (ton)

$t_i$ = age of the waste disposed in the $i^{th}$ year (years)

Reference: US EPA Landfill Methane Outreach Program: *Mexico LFG Model,* November 2003

An example of a calculation of landfill gas generation using this model can be downloaded from the internet on www.epa.gov/lmop/international.htm#3

In determining the landfill gas generation the following constraints were applied:-

- Landfill gas generation was modelled using an assumed 50% methane concentration giving a thermal energy content (Lower Heat Value) of 5 $kWh/Nm^3$ (17.9 $MJ/Nm^3$).

- Power generation was assumed to be via turbocharged spark ignition gas engines with a thermal to electricity conversion efficiency of 40%. The theoretical gas requirement at 50% methane is 500 $Nm^3/h$ per MWe. The power potential calculation has been based on a figure of 600 $Nm^3/h$ per MWe. By comparison coal fired power stations normally achieve a thermal efficiency of around 28 – 30%.

# 4 Results

The survey carried out in terms of this brief during the period June to October 2004 established that 453 sites were operational or in the process of being permitted. Of these, only 57 were either large enough or had sufficient waste input to justify investigation as potential landfill gas-to-power projects.

The 57 sites are estimated to produce some 5.02 x $10^8$ $m^3$ of recoverable landfill gas at 50% methane in 2005. Power generation estimates provided are conservative and can be expected to grow as the volume of waste landfilled in operating sites increases. The main findings and conclusions of the study of disposal sites indicate that:-

- There were numerous small landfills, but the majority of the airspace was associated with the larger landfills located in the metropolitan municipal areas. Landfill regionalisation was occurring on a significant scale, particularly in the urbanised areas.
- Throughout the country there were shortfalls in the supply of general and hazardous waste landfill airspace that complied with the *Minimum Requirements for Waste Disposal by Landfill Second Edition 1998* as produced by the Department of Water Affairs & Forestry.

Tables 2.1 to 2.9 provide the potential for landfill gas-to-power for each province. Tables 3 and 4 summarise the National LFG potential. The input data used to calculate the annual production output of each resource category in MWh.

A critical determinant in the feasibility of a landfill gas to power project is the date of planned closure. Therefore every Table dealing with the individual provincial landfill projects states the planned closure date. This is important because landfill gas will only be extracted from one third to, at most, one half of the surface area of an operating landfill site whereas, when the site closes landfill gas production from that site will be optimised because the entire surface area is available for gas extraction hence the dramatic increase in gas production related to sites that close within the planning horizon reported in the tables.

***Table 2.1: Eastern Cape Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Arlington 2005** | 1482 | 1038 | 1.73 | 1.5 | 1.5 | |
| **Arlington 2008** | 1125 | 787 | 1.31 | 1 | 1 | |
| **Arlington 2012** | 778 | 545 | 0.91 | 0.5 | 0.5 | Closed 2003 |
| **Round Hill 2005** | 0 | 0 | 0 | 0 | 0 | |
| **Round Hill 2008** | 439 | 307 | 0.51 | 0.5 | 0.5 | |
| **Round Hill 2012** | 1018 | 712 | 1.19 | 1 | 1 | Closure in 2029 |
| **Koedoeskloof 2005** | 2359 | 1651 | 2.75 | 2.5 | 1 | |
| **Koedoeskloof 2008** | 3149 | 2204 | 3.67 | 3.5 | 2 | |
| **Koedoeskloof 2012** | 3914 | 2740 | 4.57 | 4.5 | 3 | Closure in 2019 |
| **Second Creek 2005** | 550 | 385 | 0.64 | 0.5 | 0.5 | |
| **Second Creek 2008** | 417 | 292 | 0.49 | 0.5 | 0.5 | |
| **Second Creek 2012** | 289 | 202 | 0.34 | 0 | 0 | Closed in 2005 |
| **Total 2005** | 4391 | 3074 | 5.13 | 4.5 | 3 | |
| **Total 2008** | 5130 | 3590 | 5.98 | 5.5 | 4 | |
| **Total 2012** | 5999 | 4199 | 6 | 6 | 4.5 | |

***Table 2.2: Free State Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Bethlehem 2005** | 980 | 686 | 1.14 | 1 | 0 | Closure 2006 |
| **Bethlehem 2008** | 974 | 682 | 1.14 | 1 | 1 | |
| **Bethlehem 2012** | 674 | 472 | 0.79 | 0.5 | 0.5 | |
| **South Bloem 2005** | 3207 | 2245 | 3.74 | 3.5 | 1 | Closure 2030 |
| **South Bloem 2008** | 3444 | 2411 | 4.02 | 4 | 2 | |
| **South Bloem 2012** | 3673 | 2571 | 4.29 | 4 | 2 | |
| **Botshabelo 2005** | 1552 | 1086 | 1.81 | 1.5 | 0.5 | Closure 2017 |
| **Botshabelo 2008** | 2018 | 1412 | 2.35 | 2.5 | 1.5 | |
| **Botshabelo 2012** | 2469 | 1728 | 2.88 | 3 | 2 | |
| **Sasolburg 2005** | 984 | 689 | 1.15 | 1 | 0.5 | Closure 2017 |
| **Sasolburg 2008** | 1063 | 744 | 1.24 | 1 | 0.5 | |
| **Sasolburg 2012** | 1140 | 798 | 1.33 | 1 | 0.5 | |
| **Welkom 2005** | 1528 | 1070 | 1.79 | 1.5 | 0.5 | Closure 2028 |
| **Welkom 2008** | 1829 | 1280 | 2.13 | 2 | 1 | |
| **Welkom 2012** | 2121 | 1484 | 2.47 | 2.5 | 1 | |
| **Total 2005** | 8251 | 5776 | 9.63 | 8.5 | 2.5 | |
| **Total 2008** | 9328 | 6529 | 10.88 | 10.5 | 6 | |
| **Total 2012** | 10077 | 7053 | 11.76 | 11 | 6 | |

***Table 2.3: Gauteng Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Ennerdale 2005** | 1036 | 725 | 1.21 | 1 | 0.5 | Closure 2014 |
| **Ennerdale 2008** | 1121 | 785 | 1.31 | 1 | 0.5 | |
| **Ennerdale 2012** | 1204 | 843 | 1.41 | 1.5 | 1 | |
| **Goudkoppies 2005** | 5094 | 3565 | 5.94 | 6 | 2 | Closure 2039 |
| **Goudkoppies 2008** | 5571 | 3899 | 6.50 | 6 | 3 | |
| **Goudkoppies 2012** | 6033 | 4223 | 7.04 | 7 | 4 | |
| **Linbro Park 2005** | 6054 | 4238 | 7.06 | 7 | 3 | Closure 2006 |
| **Linbro Park 2008** | 6043 | 4230 | 7.05 | 7 | 7 | |
| **Linbro Park 2012** | 4181 | 2927 | 4.88 | 4.5 | 4.5 | |
| **Marie Louise 2005** | 6752 | 4727 | 7.88 | 7.5 | 3 | Closure 2024 |
| **Marie Louise 2008** | 6835 | 4784 | 7.97 | 8 | 4 | |
| **Marie Louise 2012** | 6914 | 4840 | 8.07 | 8 | 5 | |
| **Robinson Deep 2005** | 5064 | 3545 | 5.91 | 6 | 3 | Closure 2009 |
| **Robinson Deep 2008** | 5126 | 3588 | 5.98 | 6 | 4 | |
| **Robinson Deep 2012** | 4291 | 3004 | 5.01 | 5 | 5 | |
| **Rooipoort Merafong 2005** | 448 | 314 | 0.52 | 0.5 | 0.5 | Closure 2029 |
| **Rooipoort Merafong 2008** | 615 | 431 | 0.72 | 0.5 | 0.5 | |
| **Rooipoort Merafong 2012** | 777 | 544 | 0.91 | 1 | 0.5 | |
| **Luipaardsvlei Mogale 2005** | 1192 | 835 | 1.39 | 1 | 1 | Closure 2012 |
| **Luipaardsvlei Mogale 2008** | 1323 | 926 | 1.54 | 1.5 | 1 | |
| **Luipaardsvlei Mogale 2012** | 1450 | 1015 | 1.69 | 1.5 | 1.5 | |
| **Waldrift Emfuleni 2005** | 1918 | 1343 | 2.24 | 2 | 1.5 | Closure 2010 |
| **Waldrift Emfuleni 2008** | 2073 | 1451 | 2.42 | 2.5 | 1.5 | |
| **Waldrift Emfuleni 2012** | 1998 | 1399 | 2.33 | 2 | 2 | |
| **Zuurfontein Emfuleni 2005** | 629 | 440 | 0.73 | 0.5 | 0.5 | Closure 2005 |
| **Zuurfontein Emfuleni 2008** | 500 | 350 | 0.58 | 0.5 | 0.5 | |
| **Zuurfontein Emfuleni 2012** | 346 | 242 | 0.40 | 0.3 | 0.3 | |
| **Boitshepi Emfuleni 2005** | 2514 | 1760 | 2.93 | 3 | 1 | Closure 2009 |
| **Boitshepi Emfuleni 2008** | 2935 | 2054 | 3.42 | 3.5 | 2 | |
| **Boitshepi Emfuleni 2012** | 2626 | 1838 | 3.06 | 3 | 3 | |
| **Weltevreden EMM 2005** | 2747 | 1923 | 3.21 | 3 | 1.5 | Closure 2024 |
| **Weltevreden EMM 2008** | 3234 | 2264 | 3.77 | 3.5 | 2 | |
| **Weltevreden EMM 2012** | 3707 | 2595 | 4.33 | 4 | 3 | |
| **Simmer & Jack EMM 2005** | 2553 | 1787 | 2.98 | 3 | 1 | Closure 2030 |
| **Simmer & Jack EMM 2008** | 3184 | 2228 | 3.71 | 3.5 | 2 | |
| **Simmer & Jack EMM 2012** | 3795 | 2656 | 4.43 | 4.5 | 3 | |
| **Rietfontein EMM 2005** | 1580 | 1106 | 1.84 | 1.5 | 1 | Closure 2024 |
| **Rietfontein EMM 2008** | 1932 | 1352 | 2.25 | 2 | 1.5 | |
| **Rietfontein EMM 2012** | 2273 | 1591 | 2.65 | 2.5 | 2 | |

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Platkop EMM 2005** | 504 | 353 | 0.59 | 0.5 | 0 | Closure 2038 |
| **Platkop EMM 2008** | 621 | 435 | 0.73 | 0.5 | 0.5 | |
| **Platkop EMM 2012** | 734 | 514 | 0.86 | 0.5 | 0.5 | |
| **Rooikraal EMM 2005** | 5052 | 3536 | 5.89 | 5.5 | 2 | Closure 2028 |
| **Rooikraal EMM 2008** | 5465 | 3825 | 6.38 | 6.5 | 3 | |
| **Rooikraal EMM 2012** | 5864 | 4105 | 6.84 | 7 | 4 | |
| **Deerdepoort Tshwane 2005** | 2481 | 1737 | 2.90 | 2.5 | 1 | Closure 2007 |
| **Deerdepoort Tshwane 2008** | 3081 | 2157 | 3.60 | 3.5 | 3.5 | |
| **Deerdepoort Tshwane 2012** | 2131 | 1492 | 2.49 | 2.5 | 2.5 | |
| **Ga-Rankuwa Tshwane 2005** | 1884 | 1319 | 2.20 | 2 | 1 | Closure 2020 |
| **Ga-Rankuwa Tshwane 2008** | 2228 | 1560 | 2.60 | 3 | 2 | |
| **Ga-Rankuwa Tshwane 2012** | 2562 | 1793 | 2.99 | 3 | 2 | |
| **Valhalla Tshwane 2005** | 4721 | 3305 | 5.51 | 5.5 | 5 | Closure 2004 |
| **Valhalla Tshwane 2008** | 3582 | 2507 | 4.18 | 4 | 4 | |
| **Valhalla Tshwane 2012** | 2478 | 1734 | 2.89 | 2.5 | 2.5 | |
| **Onderstepoort Tshwane 2005** | 5420 | 3794 | 6.32 | 6 | 2 | Closure 2020 |
| **Onderstepoort Tshwane 2008** | 6094 | 4266 | 7.11 | 7 | 3 | |
| **Onderstepoort Tshwane 2012** | 6931 | 4852 | 8.09 | 8 | 4 | |
| **Hatherley Tshwane 2005** | 1389 | 972 | 1.62 | 1.5 | 1 | Closure 2048 |
| **Hatherley Tshwane 2008** | 1744 | 1221 | 2.04 | 2 | 1 | |
| **Hatherley Tshwane 2012** | 2088 | 1461 | 2.44 | 2.5 | 1.5 | |
| **Temba Tshwane 2005** | 899 | 719 | 1.20 | 1 | 1 | Closure 2004 |
| **Temba Tshwane 2008** | 682 | 546 | 0.91 | 0.5 | 0.5 | |
| **Temba Tshwane 2012** | 472 | 378 | 0.63 | 0.5 | 0.5 | |
| **Kwaggasrand Tshwane 2005** | 4329 | 3030 | 5.05 | 5 | 2 | Closure 2012 |
| **Kwaggasrand Tshwane 2008** | 4806 | 3364 | 5.61 | 5.5 | 3 | |
| **Kwaggasrand Tshwane 2012** | 5268 | 3688 | 6.15 | 6 | 6 | |
| **Soshanguve Tshwane 2005** | 1789 | 1253 | 2.09 | 2 | 1 | Closure 2010 |
| **Soshanguve Tshwane 2008** | 2075 | 1453 | 2.42 | 2.5 | 1.5 | |
| **Soshanguve Tshwane 2012** | 2090 | 1463 | 2.44 | 2.5 | 2.5 | |
| **Garstkloof Tshwane 2005** | 3320 | 2324 | 3.87 | 3.5 | 1.5 | Closure 2009 |
| **Garstkloof Tshwane 2008** | 3684 | 2579 | 4.30 | 4 | 2 | |
| **Garstkloof Tshwane 2012** | 3224 | 2257 | 3.76 | 3.5 | 3.5 | |
| **Total 2005** | 69369 | 48650 | 81.08 | 81 | 37 | |
| **Total 2008** | 74554 | 52255 | 87.09 | 87 | 53.5 | |
| **Total 2012** | 73437 | 51454 | 85.76 | 85 | 64.3 | |

***Table 2.4: KwaZulu-Natal Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Bisasar Road 2005** | 9503 | 6652 | 11.09 | 11 | 4 | |
| **Bisasar Road 2008** | 10534 | 7374 | 12.29 | 12 | 4 | |
| **Bisasar Road 2012** | 11534 | 8073 | 13.46 | 13 | 8 | Closure 2014 |
| **Mariannhill 2005** | 871 | 610 | 1.02 | 1 | 0.5 | |
| **Mariannhill 2008** | 1193 | 835 | 1.39 | 1 | 1 | |
| **Mariannhill 2012** | 1545 | 1081 | 1.80 | 1 | 1 | Closure 2027 |
| **La Mercy 2005** | 801 | 561 | 0.94 | 0.5 | 0.5 | Closure 2005 |
| **La Mercy 2008** | 608 | 426 | 0.71 | 0.5 | 0.5 | |
| **La Mercy 2012** | 421 | 294 | 0.49 | 0.5 | 0.5 | |
| **New England Road 2005** | 1329 | 930 | 1.55 | 1.5 | 1 | |
| **New England Road 2008** | 1586 | 1110 | 1.85 | 1.5 | 1 | |
| **New England Road 2012** | 1835 | 1285 | 2.14 | 2 | 2 | Closure 2015 |
| **Newcastle 2005** | 576 | 403 | 0.67 | 0.5 | | |
| **Newcastle 2008** | 628 | 440 | 0.73 | 0.5 | 0.5 | |
| **Newcastle 2012** | 678 | 475 | 0.79 | 0.5 | 0.5 | Closure 2019 |
| **Uthungulu Reg 2005** | 230 | 161 | 0.27 | 0 | 0 | |
| **Uthungulu Reg 2008** | 621 | 434 | 0.72 | 0.5 | 0.5 | |
| **Uthungulu Reg 2012** | 999 | 699 | 1.17 | 0.5 | 0.5 | Closure ? |
| **Richards Bay/Emp 2005** | 881 | 617 | 1.03 | 1 | 1 | Closure 2004 |
| **Richards Bay/Emp 2008** | 668 | 468 | 0.78 | 0.5 | 0.5 | |
| **Richards Bay/Emp 2012** | 462 | 324 | 0.54 | 0.5 | 0.5 | |
| **Total 2005** | 14191 | 9934 | 16.56 | 15.5 | 7 | |
| **Total 2008** | 15838 | 11087 | 18.48 | 16.5 | 8 | |
| **Total 2012** | 17474 | 12231 | 20.39 | 18 | 13 | |

***Table 2.5: Limpopo Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Makopane 2005** | 591 | 414 | 0.69 | 0.5 | 0 | Closure 2018 |
| **Makopane 2008** | 713 | 499 | 0.83 | 0.5 | 0.5 | |
| **Makopane 2012** | 869 | 608 | 1.01 | 0.5 | 0.5 | |
| **Weltevreden Polokwane 2005** | 923 | 646 | 1.08 | 0.5 | 0.5 | Closure 2016 |
| **Weltevreden Polokwane 2008** | 1072 | 750 | 1.25 | 0.5 | 0.5 | |
| **Weltevreden Polokwane 2012** | 1215 | 850 | 1.42 | 0.5 | 0.5 | |
| **Total 2005** | 1514 | 1060 | 1.77 | 1 | 0.5 | |
| **Total 2008** | 1785 | 1249 | 2.08 | 1 | 1 | |
| **Total 2012** | 2084 | 1458 | 2.43 | 1 | 1 | |

***Table 2.6: Mpumalanga Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Nelspruit 2005** | 814 | 570 | 0.95 | 1 | 1 | Closure 2005 |
| **Nelspruit 2008** | 742 | 520 | 0.87 | 0.5 | 0.5 | |
| **Nelspruit 2012** | 513 | 359 | 0.60 | 0.5 | 0.5 | |
| **Leeupoort Emahlaleni 2005** | 840 | 588 | 0.98 | 1 | 0.5 | Closure 2034 |
| **Leeupoort Emahlaleni 2008** | 1036 | 726 | 1.21 | 1 | 0.5 | |
| **Leeupoort Emahlaleni 2012** | 1227 | 859 | 1.43 | 1.5 | 1 | |
| **Middleburg 2005** | 334 | 234 | 0.39 | 0 | 0 | Closure 2031 |
| **Middleburg 2008** | 515 | 361 | 0.60 | 0.5 | 0.3 | |
| **Middleburg 2012** | 691 | 483 | 0.81 | 0.5 | 0.3 | |
| **Total 2005** | 1988 | 1392 | 2.32 | 2 | 1.5 | |
| **Total 2008** | 2293 | 1607 | 2.68 | 2 | 1.3 | |
| **Total 2012** | 2431 | 1701 | 2.84 | 2.5 | 1.8 | |

***Table 2.7: North West Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Hartbeesfontein Regional 2005** | 1183 | 828 | 1.38 | 1 | 0.5 | Closure 2020 |
| **Hartbeesfontein Regional 2008** | 1409 | 986 | 1.64 | 1.5 | 1 | |
| **Hartbeesfontein Regional 2012** | 1627 | 1139 | 1.90 | 2 | 1 | |
| **Townlands Rustenburg 2005** | 626 | 438 | 0.73 | 0.5 | 0 | Closure 2006 |
| **Townlands Rustenburg 2008** | 663 | 464 | 0.77 | 0.5 | 0.5 | |
| **Townlands Rustenburg 201** | 458 | 321 | 0.54 | 0.5 | 0.5 | |
| **Hartebeeskop Potch 2005** | 1751 | 1226 | 2.04 | 2 | 2 | Closure 2004 |
| **Hartebeeskop Potch 2008** | 1328 | 930 | 1.55 | 1.5 | 1.5 | |
| **Hartebeeskop Potch 2012** | 919 | 643 | 1.07 | 1 | 1 | |
| **Total 2005** | 3560 | 2492 | 4.15 | 3.5 | 2.5 | |
| **Total 2008** | 3400 | 2380 | 3.97 | 3.5 | 3 | |
| **Total 2012** | 3004 | 2103 | 3.51 | 3.5 | 2.5 | |

***Table 2.8: Northern Cape Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Duine Refuge //Khara Hais 2005** | 377 | 264 | 0.44 | 0 | 0 | Closure 2015 |
| **Duine Refuge //Khara Hais 2008** | 453 | 317 | 0.53 | 0.5 | 0.3 | |
| **Duine Refuge //Khara Hais 2012** | 526 | 368 | 0.61 | 0.5 | 0.3 | |
| **Kimberley 2005** | 928 | 650 | 1.08 | 1 | 0.5 | Closure 2019 |
| **Kimberley 2008** | 998 | 698 | 1.16 | 1 | 0.5 | |
| **Kimberley 2015** | 1065 | 746 | 1.24 | 1 | 0.5 | |
| **Total 2005** | 1305 | 914 | 1.52 | 1 | 0.5 | |
| **Total 2008** | 1451 | 1015 | 1.69 | 1.5 | 0.8 | |
| **Total 2012** | 1591 | 1114 | 1.86 | 1.5 | 0.8 | |

***Table 2.9: Western Cape Province Landfill Gas Potential***

| | Predicted LFG @ 50% CH4 Nm3/h | Collectable LFG @ 50% CH4 Nm3/h | Theoretical Power MWe | Potential Power MWe | Probable Power MWe 40-50% of Potential | Notes |
|---|---|---|---|---|---|---|
| **Brackenfell CMC 2005** | 977 | 684 | 1.14 | 1 | 0 | Closure 2006 |
| **Brackenfell CMC 2008** | 1071 | 749 | 1.25 | 1 | 1 | |
| **Brackenfell CMC 2012** | 741 | 518 | 0.86 | 0.5 | 0.5 | |
| **Faure CMC 2005** | 528 | 370 | 0.62 | 0 | 0 | Closure 2006 |
| **Faure CMC 2008** | 585 | 410 | 0.68 | 0.5 | 0.5 | |
| **Faure CMC 2012** | 405 | 283 | 0.47 | 0.5 | 0.5 | |
| **Coastal Park CMC 2005** | 2192 | 1535 | 2.56 | 2.5 | 1 | Closure 2017 |
| **Coastal Park CMC 2008** | 2560 | 1792 | 2.99 | 3 | 2 | |
| **Coastal Park CMC 2012** | 2915 | 2041 | 3.40 | 3.5 | 2 | |
| **Swartklip CMC 2005** | 1730 | 1211 | 2.02 | 2 | 1 | Closure 2017 |
| **Swartklip CMC 2008** | 1854 | 1298 | 2.16 | 2 | 1 | |
| **Swartklip CMC 2012** | 1975 | 1383 | 2.31 | 2 | 1 | |
| **Bellville South CMC 2005** | 2654 | 1858 | 3.10 | 3 | 2 | Closure 2006 |
| **Bellville South CMC 2008** | 2866 | 2006 | 3.34 | 3 | 3 | |
| **Bellville South CMC 2012** | 1983 | 1388 | 2.31 | 2 | 2 | |
| **Vissershok CMC 2005** | 5201 | 3641 | 6.07 | 6 | 3 | Closure 2008 |
| **Vissershok CMC 2008** | 5848 | 4094 | 6.82 | 6 | 6 | |
| **Vissershok CMC 2012** | 4572 | 3201 | 5.34 | 5 | 5 | |
| **Stellenbosch 2005** | 732 | 586 | 0.98 | 1 | 1 | Closure 2005 |
| **Stellenbosch 2008** | 555 | 444 | 0.74 | 0.5 | 0.5 | |
| **Stellenbosch 2012** | 384 | 307 | 0.51 | 0.5 | 0.5 | |
| **Total 2005** | 14014 | 9885 | 16.48 | 15.5 | 8 | |
| **Total 2008** | 15339 | 10793 | 17.99 | 16 | 14 | |
| **Total 2012** | 12975 | 9121 | 15.20 | 14 | 11.5 | |

*Table 3: All the Potentially Feasible Landfill Gas to Electrical Energy Projects arranged by Province*

| Probable Power MW e | Province | Year | | |
|---|---|---|---|---|
| Landfill | | 2005 | 2008 | 2012 |
| Ennerdale CoJ | G | 0.5 | 0.5 | 1 |
| Goudkoppies CoJ | G | 2 | 3 | 4 |
| Linbro Park CoJ | G | 3 | 7 | 4.5 |
| Marie Louise CoJ | G | 3 | 4 | 5 |
| Robinson Deep CoJ | G | 3 | 4 | 5 |
| Rooipoort Merafong City | G | 0.5 | 0.5 | 0.5 |
| Luipaardsvlei Mogale City | G | 1 | 1 | 1.5 |
| Waldrift Emfuleni | G | 1.5 | 1.5 | 2 |
| Zuurfontein Emfuleni | G | 0.5 | 0.5 | 0.3 |
| Boitshepi Emfuleni | G | 1 | 2 | 3 |
| Weltevreden EMM | G | 1.5 | 2 | 3 |
| Simmer & Jack EMM | G | 1 | 2 | 3 |
| Rietfontein EMM | G | 1 | 1.5 | 2 |
| Platkop EMM | G | 0 | 0.5 | 0.5 |
| Rooikraal EMM | G | 2 | 3 | 4 |
| Deerdepoort Tshwane | G | 1 | 3.5 | 2.5 |
| Ga-Rankuwa Tshwane | G | 1 | 2 | 2 |
| Valhalla Tshwane | G | 5 | 4 | 2.5 |
| Onderstepoort Tshwane | G | 2 | 3 | 4 |
| Hatherley Tshwane | G | 1 | 1 | 1.5 |
| Temba Tshwane | G | 1 | 0.5 | 0.5 |
| Kwaggasrand Tshwane | G | 2 | 3 | 6 |
| Soshanguve Tshwane | G | 1 | 1.5 | 2.5 |
| Garstkloof Tshwane | G | 1.5 | 2 | 3.5 |
| Nelspruit | MP | 1 | 0.5 | 0.5 |
| Leeupoort Emahlaleni | MP | 0.5 | 0.5 | 1 |
| Middleburg | MP | 0 | 0.3 | 0.3 |
| Kimberley | NC | 0.5 | 0.5 | 0.5 |
| //Khara Hais | NC | 0 | 0.3 | 0.3 |
| Bethlehem | FS | 0 | 1 | 0.5 |
| Southern Bloem | FS | 1 | 2 | 2 |
| Botshabelo | FS | 0.5 | 1.5 | 2 |
| Sasolburg | FS | 0.5 | 0.5 | 0.5 |
| Welkom Regional | FS | 0.5 | 1 | 1 |
| Makopane | L | 0 | 0.5 | 0.5 |
| Weltevreden Polokwane | L | 0.5 | 0.5 | 0.5 |
| Arlington | EC | 1.5 | 1 | 0.5 |
| Round Hill | EC | 0 | 0.5 | 1 |
| Koedoeskloof | EC | 1 | 2 | 3 |
| Second Creek | EC | 0.5 | 0.5 | 0 |
| Bisasar Road | KZN | 4 | 4 | 8 |
| Mariannhill | KZN | 0.5 | 1 | 1 |
| La Mercy | KZN | 0.5 | 0.5 | 0.5 |

| Probable Power MW e | Province | Year | | |
|---|---|---|---|---|
| New England Road | KZN | 1 | 1 | 2 |
| Newcastle | KZN | 0 | 0.5 | 0.5 |
| Uthungulu Regional | KZN | 0 | 0.5 | 0.5 |
| Richards Bay/Empangeni | KZN | 1 | 0.5 | 0.5 |
| Brackenfell | WC | 0 | 1 | 0.5 |
| Faure | WC | 0 | 0.5 | 0.5 |
| Coastal Park | WC | 1 | 2 | 2 |
| Swartklip | WC | 1 | 1 | 1 |
| Bellville South | WC | 2 | 3 | 2 |
| Vissershok CMC | WC | 3 | 6 | 5 |
| Stellenbosch | WC | 1 | 0.5 | 0.5 |
| Hartbeesfontein | NW | 0.5 | 1 | 1 |
| Hartebeeskop Potch | NW | 2 | 1.5 | 1 |
| Townlands Rustenburg | NW | 0 | 0.5 | 0.5 |
| Total | | 62.5 | 91.6 | 105.4 |
| GW h | | **492.75** | **722.17** | **830.97** |

Most of the potentially feasible projects are located in Gauteng Province, followed by the Western Cape and KwaZulu-Natal.

***Table 4: All the Potentially Feasible Landfill Gas to Electrical Energy Projects arranged in order of magnitude for 2008.***

| Probable Power MW e | Province | Year | | |
|---|---|---|---|---|
| Landfill | | 2005 | 2008 | 2012 |
| Linbro Park CoJ | G | 3 | 7 | 4.5 |
| Vissershok CMC | WC | 3 | 6 | 5 |
| Valhalla Tshwane | G | 5 | 4 | 2.5 |
| Bisasar Road | KZN | 4 | 4 | 8 |
| Marie Louise CoJ | G | 3 | 4 | 5 |
| Robinson Deep CoJ | G | 3 | 4 | 5 |
| Deerdepoort Tshwane | G | 1 | 3.5 | 2.5 |
| Rooikraal EMM | G | 2 | 3 | 4 |
| Bellville South | WC | 2 | 3 | 2 |
| Kwaggasrand Tshwane | G | 2 | 3 | 6 |
| Onderstepoort Tshwane | G | 2 | 3 | 4 |
| Goudkoppies CoJ | G | 2 | 3 | 4 |
| Weltevreden EMM | G | 1.5 | 2 | 3 |
| Garstkloof Tshwane | G | 1.5 | 2 | 3.5 |
| Coastal Park | WC | 1 | 2 | 2 |
| Koedoeskloof | EC | 1 | 2 | 3 |
| Simmer & Jack EMM | G | 1 | 2 | 3 |
| Boitshepi Emfuleni | G | 1 | 2 | 3 |
| Southern Bloem | FS | 1 | 2 | 2 |
| Ga-Rankuwa Tshwane | G | 1 | 2 | 2 |
| Rietfontein EMM | G | 1 | 1.5 | 2 |
| Soshanguve Tshwane | G | 1 | 1.5 | 2.5 |
| Hartebeeskop Potch | NW | 2 | 1.5 | 1 |
| Botshabelo | FS | 0.5 | 1.5 | 2 |
| Waldrift Emfuleni | G | 1.5 | 1.5 | 2 |
| Welkom Regional | FS | 0.5 | 1 | 1 |
| Bethlehem | FS | 0 | 1 | 0.5 |
| Mariannhill | KZN | 0.5 | 1 | 1 |
| New England Road | KZN | 1 | 1 | 2 |
| Luipaardsvlei Mogale City | G | 1 | 1 | 1.5 |
| Arlington | EC | 1.5 | 1 | 0.5 |
| Hatherley Tshwane | G | 1 | 1 | 1.5 |
| Swartklip | WC | 1 | 1 | 1 |
| Hartbeesfontein | NW | 0.5 | 1 | 1 |
| Brackenfell | WC | 0 | 1 | 0.5 |
| Sasolburg | FS | 0.5 | 0.5 | 0.5 |
| Richards Bay/Empangeni | KZN | 1 | 0.5 | 0.5 |
| Faure | WC | 0 | 0.5 | 0.5 |
| Townlands Rustenburg | NW | 0 | 0.5 | 0.5 |
| Uthungulu Regional | KZN | 0 | 0.5 | 0.5 |
| La Mercy | KZN | 0.5 | 0.5 | 0.5 |
| Temba Tshwane | G | 1 | 0.5 | 0.5 |

| Probable Power MW e | Province | Year | | |
|---|---|---|---|---|
| **Stellenbosch** | **WC** | 1 | 0.5 | 0.5 |
| **Ennerdale CoJ** | **G** | 0.5 | 0.5 | 1 |
| **Newcastle** | **KZN** | 0 | 0.5 | 0.5 |
| **Nelspruit** | **MP** | 1 | 0.5 | 0.5 |
| **Leeupoort Emahlaleni** | **MP** | 0.5 | 0.5 | 1 |
| **Rooipoort Merafong City** | **G** | 0.5 | 0.5 | 0.5 |
| **Zuurfontein Emfuleni** | **G** | 0.5 | 0.5 | 0.3 |
| **Platkop EMM** | **G** | 0 | 0.5 | 0.5 |
| **Makopane** | **L** | 0 | 0.5 | 0.5 |
| **Weltevreden Polokwane** | **L** | 0.5 | 0.5 | 0.5 |
| **Kimberley** | **NC** | 0.5 | 0.5 | 0.5 |
| **Round Hill** | **EC** | 0 | 0.5 | 1 |
| **Second Creek** | **EC** | 0.5 | 0.5 | 0 |
| **Middleburg** | **MP** | 0 | 0.3 | 0.3 |
| **//Khara Hais** | **NC** | 0 | 0.3 | 0.3 |
| **Total MW e** | | 62.5 | 91.6 | 105.4 |
| **GW h** | | **492.75** | **722.17** | **830.97** |

It must be assumed that when landfill sites close, new sites will open to accept the waste that will be generated within the previous waste catchment area so that the probable power generating capacity will be maintained.

# 5 The Bisasar Road Case Study

The eThekwini Municipality wishes to establish the first renewable energy project for Southern Africa where landfill gas will be extracted from operating landfill sites and used to generate electrical power. The project was initiated as a result of the World Summit on Sustainable Development (WSSD, Johannesburg, 2002) and is designed to utilise landfill gas from three sites within the Durban Metropolitan Area to yield 10 MW of electrical power.

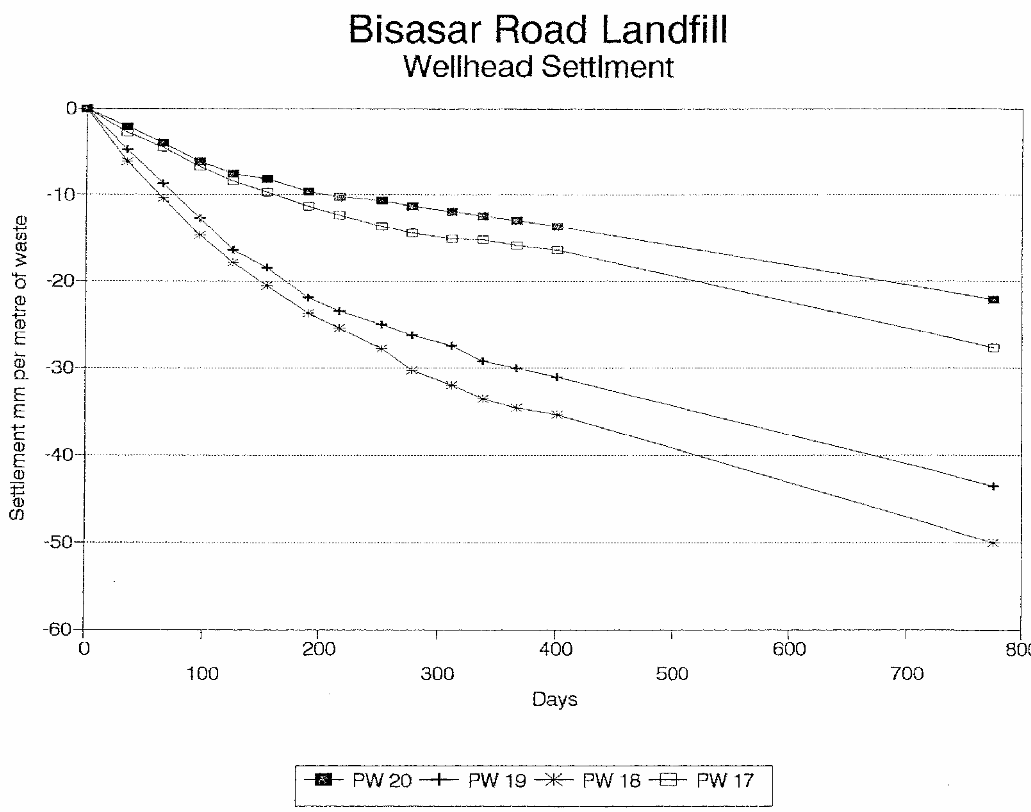
The Bisasar Road Class GLB+ Landfill is managed by Durban Solid Waste (DSW). Landfill gas problems were identified and the process of managing their impacts has begun. A detailed gas recovery investigation was carried out in order to determine the potential gas yield from this site. During the study period it was shown that the Bisasar Road Landfill site life, which was planned as being 37 years given the applicable deposition rates, would be extended by some 7 years if LFG was extracted. This would result in a saving to the Municipal Operating Budget of almost R 60 million. This 21 million cubic metre capacity landfill which was established early in 1980, is expected to serve the waste disposal needs of the city of Durban another 15 years. Bisasar Road is the busiest landfill in Southern Africa accepting a daily average of 3,500 tons of Municipal Solid Waste. The waste input has peaked at 5,200 tons at times.

There are currently thirteen (13) operational wells at the site and DSW estimate that operations will allow the installation of twenty (20) new wells by December 2004. Four of the currently operational wells will be covered due to waste deposition, thus it is planned that there will be twenty-nine (29) wells in operation by December 2004. It is planned to install more wells as waste is deposited and the site will be progressively restored from South to North.

The GasSim model used in this project predicted a peak generation of 7,600 $m^3$/h in 2014. There are existing wells in old waste to the north of the site. Gas is currently being extracted from these at 350 $m^3$/h, and this has been taken as the baseline. The baseline has been predicted to reduce in accordance with the GasSim Model. A yield of 50 $m^3$/h was recorded for a newly constructed well at the site. Although the wells are fairly deep, the gas yield from the wells will decrease exponentially over time and is expected to drop to a yield of approximately 30 $m^3$/h after 20 years. The maximum achievable extraction efficiency of the gas system is assumed to be 80 % of the gas produced (Strachan, L & Chronowski, R. 2004).

An interesting benefit related to extracting landfill gas from the Bisasar Road Landfill has been the accelerated settlement that has been recorded. The elimination of feedback inhibition on biodegradation, through landfill gas extraction, facilitates major mass transfer processes in the landfill site. Settlement is typically irregular and difficult to predict as the waste is normally highly variable. Settlement rates in areas subjected to active extraction in the Bisasar Road landfill varied from 15 - 30 mm per metre of landfilled waste depth over a period of some 400 days. Bisasar Road Landfill has shown an average settlement of over 2 m on the bottom terrace over a period 780 days. See inserted graph below. Whereas, a settlement curve for waste of a similar composition (52% builders rubble and soil) deposited on the nearby Springfield Park Landfill Site without landfill gas extraction showed settlement in the range of 5 - 9 mm per metre refuse depth landfilled over a period of 700 days.

Figure 3: Bisasar Road Landfill Wellhead Settlement




PW: Production Well

Reference: Lombard & Associates on behalf of DSW.

# 6 Feasibility Checklist

Landfill operators must be encouraged to maintain up to date, accurate and easily accessible records that meet the requirements of the Project Feasibility Checklist provided, designed to assist landfill operators with the assessment of the viability of their operations with respect to power generation. This Project Feasibility Checklist was developed by the CaBEERE Project Team to assist Independent Power Producers with the development of renewable energy projects that use landfill gas.

## 6.1 Contact Details and Classification of the Landfill Site

| | |
|---|---|
| Name of site | |
| Owner of site and contact details | |
| Operator of site and contact details | |
| Area/District/Town/City | |
| GPS Co-Ordinates | |
| Altitude in metres above msl | |
| Landfill Type, i.e. Valley, Excavation or Above Ground | |
| Waste Footprint area $m^2$ | |
| Area Available Immediately for Gas Well Installation $m^2$ | |
| Area available at Closure for Gas Well Installation $m^2$ | |
| Total Airspace $m^3$ | |
| Remaining Airspace $m^3$ | |
| In-Place Volume $m^3$ | |
| Input Data for Previous 15 years to Dec 2003 | |
| **Waste Types by Year:** | |
| % Domestic Waste | |
| % Garden Waste | |
| % Industrial, i.e. Putrescible sludges, etc. | |
| % Dry Industrial | |
| % Construction Rubble | |
| % Cover | |
| Apply the DWAF Minimum Requirements for Waste Disposal by Landfill Site Classification System to classify the sites – only the larger medium G landfills and the Large G landfills will generally prove viable. | |
| Distance to closest 11kV Power Line and power consumption related to that line | |
| Any Industry capable of using raw LFG as thermal power within 3-5km. | |

## 6.2 Environmental Monitoring of the Landfill Site

| | |
|---|---|
| Monitoring probes: | |
| Installation outside waste fill on site boundary | |
| Installation in areas of perceived risk, e.g. disturbed ground, faults, man-made structures, including buildings | |
| Record keeping system that is readily accessible | |
| GPS Co-Ordinates for monitoring probes | |
| Monitoring of $CO_2$ $CH_4$ and $O_2$ with Atmospheric Pressure | |
| Monitoring frequency once a quarter | |
| EIA Studies may be required even though the landfill has a Permit in terms of the Minimum Requirements | |
| | |

## 6.3 Landfill Gas For Power Generation – Site Selection

| | |
|---|---|
| **Area** – Minimum 6 – 7 Ha or 20 wells at 2500 – 2800 m2/wells | |
| **Depth** – Minimum 8 – 10m, Average 20 – 30m | |
| **Total Airspace** – Minimum 1.8 – 2.0 x $10^6$ $m^3$ | |
| **Annual Waste Input** – 50 000 tonnes (including cover) | |
| **Site Life** – No limits | |

## 6.4 Landfill Gas for Flaring – Site Selection Criteria

| | |
|---|---|
| **Area** – Minimum 2.5 – 3.0 Ha or 10 wells at 2500 – 2800 m2/wells | |
| **Depth** – Minimum 8 – 10m, Average 20 – 30m | |
| **Total Airspace** – Minimum 0.5 x $10^6$ $m^3$ | |
| **Annual Waste Input** – 25 000 tonnes (including cover) | |
| **Site Life** – No limits | |

## 6.5 Determining SEGP Costs

In determining an annualised cost for a Standard Electricity Generating Plant (SEGP), two categories of costs need to be determined:

- capital costs and
- operating costs (including maintenance costs)

### 6.5.1 Capital Costs

An estimate of the cost of constructing each SEGP must be made. Capital costs are broken down into the following categories:

- Civils: this category includes elements such as foundations, roads, dams, etc – essentially, anything that is built mostly using concrete;
- Buildings: any structures that are built using bricks and cement. This category is sub-divided into: Residential Buildings (for operating staff) and Commercial Buildings (i.e. offices, storerooms, production facilities, etc.);
- Mechanical equipment;
- Electrical equipment, and
- Other: anything that cannot be placed in any of the above categories (i.e. professional fees, EIA costs, etc.)

The main purpose of this breakdown is to enable a more accurate analysis of the economic impacts of the projects.

### 6.5.2 Operating Costs

Annual operating costs have been estimated and include:

- Consumable Input Costs: this includes anything that will be used in order to operate an SEGP (i.e. oil, fuel, rent, etc.)
- Direct Staff/Labour Costs: this includes all costs associated with employing people to operate and maintain an SEGP (i.e. wages and salaries, contributions to medical aid, pension, insurances, vehicle allowances, etc.)
- Indirect Overhead Costs: this includes all of the costs of managing an SEGP (i.e. general management, marketing, finance costs, etc.)

Staff/labour must be broken down into: Skilled, Semi-Skilled and Unskilled categories and information must be provided for the number of people employed in each category and the annual costs for an individual in each category.

### 6.5.3 Maintenance Costs

Every SEGP will require a certain amount of ongoing maintenance over its lifetime. Maintenance is calculated as a percentage of the original capital costs, spread across the life of each capital item.

### 6.5.4 Local vs. Imported Costs

An estimate needs to be made of the proportion of the capital and operating costs that will be sourced from local South African suppliers, or that will need to be imported from foreign suppliers.

# 7 Conclusion & Recommendations

South Africa has a substantial potential energy resource from landfill gas within the major conurbations. A survey carried out in terms of this brief during the period June to October 2004 established that 453 sites were operational or in the process of being permitted. The site selection process led to the evaluation of 57 Sites throughout South Africa which were analysed to determine the potential electrical power that could be extracted from the production of landfill gas. The sites were screened based on their size, the nature of the waste disposed in the sites and the possible methane production was modelled using a modification of the European developed Tabarasan Model.

This study has demonstrated that it is possible to use power generation from landfill gas as a major contributor to meet the renewable energy targets set by Government for 2013. This resource should be utilised as part of the national energy mix.

The 57 sites that have emerged as feasible in terms of this study are estimated to be capable of making a significant contribution to the RE target as follows:

| | | |
|---|---|---|
| 2005 | 63 MW | approximately 493 GWh/annum |
| 2008 | 92 MW | 722 GWh/annum |
| 2013 | 105 MW | 831 GWh/annum |

It is important to note that the power generation estimates provided are conservative and can be expected to grow as the volume of waste landfilled in operating sites increases. The power generation estimates may vary depending on when landfill sites close because, on closure, the entire landfill site may be degassed simultaneously whereas operational landfill sites have restricted degassing opportunities. The available GWh have been calculated on the basis of a conservative 90% plant availability which, together with the conservative approach that has been adopted throughout this study suggests that it is not unlikely that the energy yields might be expanded by as much as 20%.

The main findings of the study of disposal sites indicated the following:

- There are numerous small landfills, but that the majority of the airspace, and thus power generation opportunities, are associated with the larger landfills located in the metropolitan municipal areas.
- Landfill regionalisation is occurring on a significant scale, particularly in the urbanised areas and this trend should be encouraged both for environmental control and the potential for energy recovery.
- Although 57 landfill sites have potential relative to the conversion of landfill gas to electrical energy, it is clear that the 20 best opportunities yield close to 70% of the probable energy which will make a considerable contribution to the 2013 RE target.

A case study dealing with Ethekwini Metropolitan Council's landfill gas to electrical energy project, which is presented in Chapter 5 of this report, has corroborated the findings of this study.

The landfill sites were mapped using a GIS employing layers that included the site names, size, tonnage input of solid wastes and potential landfill gas extracted projected by site. A separate listing has been prepared by province of the landfill sites that have potential to generate electricity using landfill gas. Landfill gas projects should focus on the three provinces with the greatest potential i.e. Gauteng, Kwa-Zulu Natal and the Western Cape.

Landfill operators must be encouraged to maintain up to date, accurate and easily accessible records that meet the requirements of a Project Feasibility Checklist that was developed, as presented in Chapter 6. A great deal of time was required to recover data from local municipalities that had not maintained readily accessible waste information systems. It will also be useful for future projects if local municipalities operating larger landfill sites, particularly those among the top 57 sites that have been identified in the country, could maintain records of gas monitoring probe data to be used as basic inputs for determining energy project feasibility. Developers should be encouraged to utilise the Project Feasibility Checklist when assessing the potential of using landfill gas as a source of energy.

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# Appendix 1: Landfill Gas Management

# Appendix 2: Mapping

# Appendix 3: Example of the Determination of Landfill Gas Yields and Potential Power

# Appendix 4: Bisasar Road Landfill Case Study

# Appendix 5: TOR