REALISING LANDFILL GAS POTENTIAL FOR CLIMATE CHANGE AND RENEWABLE ENERGY GOALS

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ABSTRACT

There is a crucial linkage between renewable energy technologies, combating climate change and the realisation of carbon-based emission reductions. In particular, the extraction and utilisation of landfill gas offers a viable *green power* source, as well as a significant contributor to global greenhouse gas emission reductions if appropriately utilised. In fact, the South African Department of Minerals and Energy (DME) have estimated, in recent research surveys, that at least 6% (some 100 MW) of the country's renewable energy target should be derived from landfills. This paper presents a landfill gas utilisation project that, in August 2005, planned to realise in excess of 3.8 million tons of carbon emission reduction equivalents (CO_2e), and stood to become the world's largest Clean Development Mechanism (CDM) project. The eThekwini Municipality commenced with the *Durban Landfill Gas to Electricity CDM* project during early 2002. The project planning, engineering and development costs, including costs obtained from recent tender processes, are described in this paper. Unfortunately, a protracted Environmental Impact Assessment (EIA) process, the appeals of individuals of the public, combined with the bumbling actions of the regulation authorities, has effectively stalled this project. However, the knock-on advantages to the African continent, through an effective NEPAD (New Partnerships for African Development) initiative, are significant as a result of this proposed project. In fact, the impact both in Africa and internationally is high and the eThekwini Municipality have been approached by several other cities and entities worldwide seeking technical assistance with landfill gas utilisation CDM projects. Case studies of proposed projects in Maputo (Mozambique), Kampala (Uganda), Tehran (Iran) and Kuala Lumpur (Malaysia) are presented in this paper, along with an update of the status of CDM project registration throughout the world.

Keywords: Climate Change, Renewable Energy, Clean Development Mechanism (CDM), NEPAD, Landfill Gas Utilisation, Landfill Emissions, EIA process.

INTRODUCTION

But when his disciples saw it they had indignation, saying, "To what purpose is this waste? For this ointment might have been sold for much, and given to the poor". (Matthew 26.8-9)

Waste as a resource, is a realisable albeit not a new concept. Waste can indeed offer purpose and revenue to people, in particular to the poor. The mass transfer process of waste in landfills, which undergoes biological, chemical and physical transformation, gives rise to the formation of landfill gas. Landfill gas (LFG) offers a valuable "ointment" that can be utilised to generate power, and when placed in the arena with combating climate change, renewable energy, CDM's and sustainable development, the social advantages can be significant. In fact, the spotlight has illuminated job creation and/or Social Benefit in South Africa as a result of the implementation of renewable energy and CDM projects (DME, 2004).

The presence, formation and composition of landfill gas have been the subject of widespread detailed study in the last four decades. Early literature on landfill gas was derived arguably from the milestone works of Farquhar and Rovers (1973), Ham and Bookter (1982) and Stegmann (1982). Ham and Bookter (1982) studied landfill gas back in 1966, by initiating a project to study landfill gas and liquid emissions from landfill test cells over a monitoring period of 6~7 years. It is by now widely known that the main components of landfill gas are methane (CH_4) and carbon dioxide (CO_2). Further to this, it is widely accepted that the high concentration of methane occurring in landfill gas, typically up to 60% by volume (Christensen et al, 1996), presents an explosion risk yet a viable source of power.

Landfill gas control started in the USA in the late 1960's and early 1970's, where large landfills had been developed (Christensen, Cossu and Stegmann, 1996). The first plant to extract and utilise landfill gas was commissioned in Europe in Germany in the mid 1970's, incorporating a great deal of experience gained in the USA. The first utilisation of landfill gas in South Africa was arguably the Robinson Deep landfill gas scheme in the 1980's where a goldmine gold ore extraction process utilised the landfill gas. The next landfill gas extraction projects in South Africa were then spear-headed in the early 1990's by DSW (Durban Solid Waste, City of Durban – now the Department of Cleansing and Solid Waste of the eThekwini Municipality) and have been sustained till present day. The largest gas extraction project currently in South Africa is that of DSW's Bisasar Road Landfill site with an installed extraction capacity of some 3,000 Nm^3/hr of landfill gas. However, this project was commissioned back in 1996 and, with the termination of available funds to such projects owed to pressing social priorities elsewhere in the new municipal area of eThekwini, most gas extraction systems are today largely defunct. This latter fact has strangely, added benefit to a later baseline study that was carried out for the CDM project.

At the Bisasar Road Landfill Site, methane gas emissions alone, at approximately 50% of LFG by volume, will amount to some 25 000 tons per annum when active gas extraction is increased for proposed electricity generation demands. Methane presents a carbon gas emission that is stated to be twenty-one times more potent than carbon dioxide, in terms of its global warming potential as a recognised greenhouse gas (GHG). This factor of 21 is often referred to as the financial "Methane Kick" of a Landfill Gas based project, as it is multiplied by the tons of methane emissions to provide equivalent carbon dioxide emissions (CO_2eq). This project financial kick, that paves an immediate way to CDM project viability with landfill sites, is a prime reason as to why landfill gas utilisation projects have been referred to as the "Low Hanging Fruit" type projects.

GOOD WARMING WORLD!

"The environmental hourglass is rapidly running out. With the very survival of our beautiful islands – truly the last paradise – at stake, I urge every government and every individual to act now to save the world environment and our beloved country". (His Excellency Mr Maumoon Abdul Gayoom, President of the Republic of Maldives, 30th March 2001; See, 2001).

It is now widely accepted that climate change due to man's actions is occurring, and measures need to be taken to control the rate of climate change and the impact from climate change. A common misconception of many, particularly South Africans, is that *dirty emissions* to the atmosphere are derived from the actions of the developed industrialised countries. Although it may indeed be true that Africa is the world's lowest emitter of carbon, South Africa is the seventh (7th) highest per capita emitter of carbon dioxide globally (African Energy Journal, March-April 2005). South Africa's high CO_2 emissions are largely attributed to the population's dependence on coal-fired energy. There is lobbying in both South Africa and the UK for nuclear power because of the requirement for *sustained* (certainly not *sustainable* in the view of the authors of this paper!) levels of power, and that it does not impact on climate change despite the long term danger from radioactive waste. Whilst nuclear energy could be debated to be cleaner than coal derived power, the argument stimulates the demand for seeking alternative energies that can be obtained from renewable substances. The South African government have recently issued a *Renewable Energy White Paper 2003 – 2013* which sets out a 10-year target for realising renewable energy implementation in South Africa. This renewable energy target of some 10 000 GWh (approximately 4% of the estimated electricity demand of South Africa of 41 593 MW by 2013), is to be derived through joint contributions from biomass, wind, solar, landfill and small-scale hydro projects. Electricity generated from renewable energy sources is termed *renewable energy* or *green power* (DME Green Power publication, 2003).

RENEWABLE GREEN LANDFILL GAS POWER

Durban landfill gas to electricity generation CDM project is capable of producing 10MW of *green power*. The Bisasar Road Landfill could generate 6~8MW of sustained power for some 10 to 12 years whilst the Mariannhill and La Mercy landfills could offer some 2MW of renewable energy power. The Durban project is planned to adopt proven technology of feeding the landfill gas into purpose-built spark-ignition engines each with a 500 KW to 1MW electricity generation capacity. The electricity will be fed directly into Durban's grid. Colloquially speaking, the eThekwini Municipality is not going to *"reinvent the wheel"* with the most current best environmental and economic practice of treating landfill gas, but will ensure that the most current technology is procured. The project procurement will seek equipment that offers the most effective environmental as well as economical package to the life of the project deal of some 12 to 14 years. Landfill gas generators can vary greatly from brand to brand, in terms of performance, durability and running costs. However, the extent of environmental emissions will be crucial. The assessment research of Gillett, Gregory and Blowes (2002) reflects that certain generators may have high "gas-leaks" in their systems and offer unreliable regulation of exhaust emissions. It will be essential that eThekwini procures the right equipment for the green power job! Also, flares will be specified as closed high temperature type flares.

GROWING CDM PROJECTS

"The coming into force of the Kyoto Protocol is a major stride forwards in the fight against global climate change and global warming", said Mr Marthinus van Schalkwyk, the Minister of Environmental Affairs and Tourism (Press, Feb 2005). This may indeed be true, but the strides being taken to realise emission reductions soon, through Kyoto's flexible mechanism of the CDM are being taken by other countries. To date (at end of August 2005) of the 16 registered CDM projects internationally, there is only one registered CDM projects from the African continent (South Africa's Kuyasa Project), whilst India clearly strides ahead with 4 registered CDM projects. Brazil, stride forward with the most landfill CDM projects being the Nova Gerar and the Salvador da Bahia Landfill Landfill Gas CDM Projects. To note, in comparison to the Durban Landfill Gas CDM project, each of these projects is almost equal only to the Mariannhill Landfill Component that Strachan et al (2003) reported to be some 1.2 million tons CO_2e. Table 1 below (UNFCCC, Aug. 2005) shows the number of registered CDM projects as at the end of August 2005. In table 2 below, however, in the tabulation of projects awaiting registration, more African CDM projects appear as Morocco introduce two of their proposed wind-farm energy CDM projects. The 1st-CDM-project-for-Africa, the Kuyasa project, shows in table 1 to be registered for 6 580 CER, but is reported to be able to offer total carbon dioxide emission reductions of some 5 500 tons per annum (Renewable Energy Journal, March-April 2005). Albeit significantly less than the some 400 000 tons per annum offered by the Durban Landfill Gas project, the Kuyasa project does offer the first CDM project to South Africa and the African continent and sets out as a pathfinder for realising more CDM projects.

Table 1: Registered CDM Projects by the CDM Executive Board (as at end of August 2005)

No.	Date Registered	Project Title	Host Parties	Other Parties	Methodology *	Reductions **	Ref
16	27 Aug 05	Kuyasa low-cost urban housing energy upgrade project, Khayelitsha (Cape Town; South Africa)	South Africa		AMS-I.C. AMS-II.C. AMS-II.E.	6 580	0079
15	19 Aug 05	La Esperanza Hydroelectric Project	Honduras	Italy	AMS-I.D.	37 032	0009
14	15 Aug 05	Salvador da Bahia Landfill Gas Management Project	Brazil	Japan United Kingdom of Great Britain and Northern Ireland	AM0002	664 674	0052
13	06 Aug 05	Clarion 12MW (Gross) Renewable Sources Biomass Power Project	India		AMS-I.D.	26 300	0075
12	18 Jul 05	5 MW Dehar Grid-connected SHP in Himachal Pradesh, India	India		AMS-I.D.	16 374	0035
11	18 Jul 05	Graneros Plant Fuel Switching Project	Chile	Japan	AM0008	19 438	0024
10	26 Jun 05	Huitengxile Windfarm Project	China	Netherlands	AM0005	51 429	0064
9	03 Jun 05	Santa Cruz landfill gas combustion project	Bolivia		AM0003	82 680	0048
8	03 Jun 05	Cortecito and San Carlos Hydroelectric Project	Honduras		AMS-I.D.	37 466	0051
7	23 May 05	Biomass in Rajasthan – Electricity generation from mustard crop residues	India	Netherlands	AMS-I.D.	31 374	0058
6	23 May 05	e7 Bhutan Micro Hydro Power CDM Project	Bhutan	Japan	AMS-I.A.	524	0062
5	23 Apr 05	Cuyamapa Hydroelectric Project	Honduras		AMS-I.D.	35 660	0045
4	24 Mar 05	HFC Decomposition Project in Ulsan	Republic of Korea	Japan	AM0001	1 400 000	0003
3	08 Mar 05	Project for GHG emission reduction by thermal oxidation of HFC 23 in Gujarat, India.	India	Japan Netherlands United Kingdom of Great Britain and Northern Ireland	AM0001	3 000 000	0001
2	11 Jan 05	RIO BLANCO Small Hydroelectric Project	Honduras	Finland	AMS-I.D.	17 800	0028
1	18 Nov 04	Brazil NovaGerar Landfill Gas to Energy Project	Brazil	Netherlands	AM0003	670 133	0008

Table 2: CDM Project Requests submitted for registration (UNFCCC, end of August 2005)

Ref	*CDM Project Title*	*Period for requesting review*	*Host Parties*	*Other Parties*
0072	Landfill gas extraction on the landfill Villa Dominico, Buenos Aires, Argentina	21 Jul 05 - 16 Sep 05	Argentina	Netherlands
0078	Landfill Gas Extraction and Utilization at the Matuail landfill site, Dhaka, Bangladesh	21 Jul 05 - 16 Sep 05	Bangladesh	
0042	Tétouan Wind Farm Project for Lafarge Cement Plant	24 Aug 05 - 22 Sep 05	Morocco	France
0080	SRS Bagasse Cogeneration Project	24 Aug 05 - 22 Sep 05	India	United Kingdom of Great Britain and Northern Ireland
0081	LOS ALGARROBOS HYDROELECTRIC PROJECT (PANAMA)	01 Sep 05 - 30 Sep 05	Panama	Spain
0089	Vaturu and Wainikasou Hydro Projects	01 Sep 05 - 30 Sep 05	Fiji	United Kingdom of Great Britain and Northern Ireland
0037	Rio Azul landfill gas and utilization project in Costa Rica	16 Aug 05 - 12 Oct 05	Costa Rica	Netherlands
0030	Essaouira wind power project	01 Sep 05 - 28 Oct 05	Morocco	

- AM - Large scale, ACM - Consolidated Methodologies, AMS - Small scale
  ** Estimated emission reductions in metric tonnes of CO2 equivalent per annum (as stated by the project participants)

In accordance with the modalities and procedures for a CDM (Annex decision 17/CP.7): 41 - the registration by the CDM Executive Board shall be deemed final eight weeks after the date of receipt by the Executive Board of the request for registration, unless a Party involved in the project activity or at least three members of the Executive Board request a review of the proposed CDM project activity. The review by the Executive Board shall be made in accordance with the following provisions:

(a) It shall be related to issues associated with the validation requirements;

(b) It shall be finalized no later than at the second meeting following the request for review, with the decision and the reasons for it being communicated to the project participants and the public. (UNFCCC, Aug. 2005).

LANDFILL GAS CDM PROJECTS – "THE OVER RIPENED FRUIT"

Driving around the EIA Bend

From the outset of CDM projects, landfill gas projects may have been viewed as the most viable and easiest to implement, offering a perception of quick access to realising emission reduction credits. An omnipresent description phrase to landfill gas CDM projects has been "low hanging fruit". Whilst for certain countries this may be true, the NIMBY (not in my backyard) syndrome that have historically attached itself to landfill sites, has also grabbed onto the viable landfill gas CDM project. This is pertinent to the proposed project in Durban, South Africa which has effectively locked the project into a protracted EIA process. The public opposition to the existence of landfill sites has shown, in this EIA process, to display high prominence and culminated in project appeals. In addition, a public misunderstanding of the CDM has also arguably stifled the EIA process with certain members of the public suddenly appearing as 'anti-CDM activists'. Table 3 below, shows the project steps taken by eThekwini to date.

Table 3: The Sequence of Events for the eThekwini's Durban Landfill Gas to Electricity CDM Project

Description of the eThekwini's Durban Landfill Gas CDM Project Step	*Dates*
- First contact with PCF/World Bank and concept of "Carbon Finance" –	November 2001
- First met the PCF in South Africa –	Feb-April 2002
- Letter to the Mayor of from PCF/World Bank –	May 2002
- PCF/DBSA training workshop on CDM –	June 2002
- Dr Ken Newcombe (PCF) – Mayor Mlaba meeting at WSSD 2002 –	August 2002
- Letter from DNA (then DEAT) of Conditional Approval for CDM project –	November 2002
- MOU between eThekwini and PCF –	February 2003
- Aide Memoire for Terms Sheet –	March 2003
- UNDP/DANIDA/SSN Workshop –	May 2003
- Report to full Council and EXCO on Project –	June 2003
- Council Approval –	July 2003
- Commence EIA's –	July 2003
- Adhoc Approval for funds –	October 2003
- ERPA Signing (Conditional to EIA's) –	June 2004
- ROD's for Mariannhill and La Mercy ("Component One") –	July 2004
- Appeal against "Component One" by a Mr Childs –	August 2004
- Appeal response to Minister of DAEA for "Component One" –	September 2004
- ROD Bisasar ("Component Two") –	October 2004
- Air Studies carried out by Enviros in response to ROD's requirements (both Components) -	December 2004
- Response on Appeal by Minister/DAEA on "Component One" (Approval of a "Pilot Project" only) –	February 2005
- Kyoto Protocol officially came into force with Russia's entry -	February 2005
- Appeal against DAEA's response on "Component One" (On their approval of a "Pilot Project" only) –	April 2005
- Appeal response to Minister of DAEA for "Component Two" –	May 2005
- Decision by eThekwini and World Bank's PCF to proceed with "Component One" (La Mercy and Mariannhill) on the current decision and to request a review of the decision by the DAEA -	June 2005
- Submission of Air Quality data (additional info) to Minister (Bisasar) and DAEA (M/Hill + La Mercy)-	August 2005
- Approval from World Bank and Council to proceed with Component One Construction separately -	?
- Submission of Comp. One's Application for Host Country CDM Project Approval by DNA –	?
- Start construction component One (M/Hill and La Mercy) -	?
- ROD appeal response for Component Two from MEC (DAEA) –	?
- Submission of Comp. Two's Application for Host Country CDM Project Approval by DNA –	?
- Start construction Component Two (Bisasar Road) -	?

The Durban CDM Project Barometer

During the first quarter of 2005, South Africa moved from eleventh to ninth place rating of CDM host countries (Point Carbon, 2005). This has resulted largely from the regulations under Section 25(3) of the National Environmental Management Act, 1998: Establishment of a Designated National

Authority for the Clean Development Mechanism (CDM) that was gazetted on the 24th December 2004. The growth in CDM project activity in South Africa will offer greater confidence to possible project developers and investors in the country. A project, like a landfill gas utilisation project, is indeed made viable through the recent possibility to sell carbon credits, and the possibility of obtaining what is now referred to as "Carbon Finance" for overall project development. However, the project is still effectively "owned" by the project entity, and the financial performance is based on the sale of commodities, for example the sale of carbon credits and the sale of power (as is the case in the Durban project). *"Don't forget, this is your project"* (Chronowski, 2003) is a crucial statement that must be understood by any CDM project developer or project owner.

The growing of a CDM project must ensure upon the sustained growth of the project's human resource capacity, and crucially there must be sustained involvement of a or *the* "project champion" person. The latter is so often found to be a vital project component! The City of Durban (eThekwini Municipality) have adopted a passionate CDM project strategy to "home grow" expertise internally, to utilise the project to ensure that people are empowered both technically and economically, and international expertise is effectively transferred to South Africans. This strategy has already *kicked-off* with promising young engineers at university being offered financial education assistance by the Municipality with the aim of building engineering expertise internally. Furthermore, the eThekwini Municipality are considering the establishment of a CDM-carbon trading/renewable energies special projects office. There are indeed several other project options for eThekwini, for example composting, biomass-to-energy, small hydro, solar power utilisation for the Municipality's large-scale housing developments, and alternative energy introduction projects.

Unpicked CDM fruit

The proposed Durban landfill gas utilisation CDM project is to comprise the installation of gas extraction and generating equipment on three of Durban's landfill sites with the capacity of generating a total of 10MW of continuous electrical power supply to the grid (Strachan et al, 2003). The agreement is to be for a 21 year carbon credits funding period – comprising three 7 year renewable periods. The successful development of this project could provide an internal rate of return to the municipality in excess of 25% for the City. The project agreement (with the Prototype Carbon Fund (PCF) of the World Bank) will be for the sale of 3,8 million tons emission reductions, at the rate of $3,95 per ton over a maximum period of 21 years. Of this amount, it is agreed that an agreed rate per ton must be credited to a social benefit. In this regard the PCF has agreed that the total amount that the project will generate for the social benefit project may be payable "up front". The City is to identify suitable community projects for this social benefit payment, which are to meet with the City's sustainable development criteria.

Social benefits also extend far beyond this as a result of the project going ahead, for example the "home grown" expertise strategy discussed earlier in this paper. Further developments, in 2005, have been the PCF's offer to increase the payable CER price to in excess of US$5.00 per ton. The latter event is indicative of the valuable "sitting on the same side of the negotiating table" that is required with the pioneering of such CDM projects. However, it is also explicitly understood that one must *"build the stadium and they will come"* (Field of Dreams, 1993) with CDM project development – and landfill gas utilization projects overall for that matter. To date eThekwini have liaised with several other municipalities and entities in South Africa, in Africa and world wide, several of whom look set to develop their project before Durban. The mere value of every day lost to Durban on this CDM project, in terms of the sale potential of CER and electrical sales, amounts to some R20 000.00 per day – this excluding the 'income' of environmental benefit. Indeed, in the case of the eThekwini's Durban Landfill Gas CDM Project – this fruit is already over-ripe!

THE CDM PROTOTYPE – THE DURBAN LANDFILL GAS TO ELECTRICITY PROJECT

The World Bank's Prototype Carbon Fund (PCF) is most appropriately the funding mechanism for South Africa's prototype CDM project ie. The eThekwini Municipality's Durban Landfill Gas to Electricity CDM Project. This project was conceptualised in early 2002 and was rapidly brought into a position of pre-CDM registration following completion of a baseline methodology, project design document (PDD), project monitoring plan and receipt of conditional host country approval (by DEAT at that time, now DME). In fact, a proudly South African result was the development of the ***Approved baseline methodology AM0010*** that can be viewed on the UNFCCC's (United Nations Framework Convention on Climate Change's) website, entitled: ***"Landfill gas capture and electricity generation projects where landfill gas capture is not mandated by law"; Source:*** *This methodology is based on the Durban Landfill Gas to Electricity Project in South Africa, whose project design document and baseline study, monitoring and verification plan were prepared by EcoSecurities Ltd. (version 14 July 2003) for the Carbon Finance Unit of the World Bank.*

The project has been split into two project components owed to the anticipated time lengths for environmental acceptance of each. Component One comprises the Mariannhill and La Mercy landfill sites which are planned to deliver some 700,000 Certified Emission Reductions (CER) to the PCF and Component Two, the Bisasar Road Landfill, is planned to deliver some 3.1 million CER. The Emissions Reductions Purchase Agreement (ERPA), shown in figure 6, is for a total delivery of 3.8 million CER, with an allowance of an additional 70,000 tons per annum that may be sold to any other entity provided that Component Two is commissioned. The anticipated gas generation is almost double of what is to be sold to the PCF, as shown in table 4 below. The gas generation was calculated using the GasSim and Enviros models and conservative factors have been applied for its extraction and utilisation.

Table 4: The CER in tons CO_2 equivalent for the Durban LFG to Elec. CDM Project.

Site	***Methane Destruction***	***Electricity Generation***	***TOTAL***
Bisasar Road	5,295,296	800,704	6,096,000
Mariannhill	1,112,568	112,344	1,224,912
La Mercy	488,972	24,511	513,483
TOTAL	**6,896,836**	**937,559**	**7,834,395**

Expected CER generation over the life of some 21 years has been assessed. Calculations allow for early closure on the Bisasar Road Landfill.

Component One **– La Mercy and Mariannhill Landfills**

Waste is to be deposited at the Mariannhill landfill beyond 2024, and it is predicted that 1775Nm³/hr will be produced by 2024. There are 6 existing gas wells on the site currently producing 170m³/hr. This was taken as the project baseline, reducing in accordance with the GasSim model. A further 27 gas wells are to be constructed at the site. It is predicted that newly constructed wells will yield 50m³/hr as waste is disposed from now until 2024. However, it is again expected that the yield for these wells will decrease exponentially and follow a similar trend to the wells at the other sites. Calculations show that gas utilisation equipment up to a capacity of 1.5MW will be required after 2020. If a greater gas yield is sustained, then larger engines may be installed.

Wells at the La Mercy landfill will be initially installed to extract the gas in the southern area of the site (in 2005 it is hoped!) and the northern area from 2007/8 onwards. The waste at LaMercy site is shallower than Bisasar Road and Mariannhill and a theoretical maximum of 30 m^3/hr gas yield for each well has been taken. This flow rate was assessed both from limited research trials and experience of the site. Gas production at La Mercy is calculated to peak at 770m^3/hr when the site is closed in mid-2006. Given that there should be 25 wells installed by 2006 the theoretical maximum yield for each well given 80% efficiency of gas collection can be calculated to be 23 m^3/hr. After landfill rehabilitation capping is complete, the gas extraction is taken to follow the GasSim gas production model curve at 80% efficiency. It is planned to initially install a 500kW generation unit at the La Mercy Landfill and to only increase this capacity if gas production performance exceeds the predictions significantly. The calculations include a 0.5MW engine from 2008 to 2013.

Component Two **- Bisasar Road Landfill**

It is planned to dispose of waste at Bisasar Road until around 2014. The GasSim model predicts a peak generation of 7,600m^3/hr in 2014. There are 30 existing wells in old waste to the north of the site. Gas is currently being extracted from these at 329m^3/hr, and this has been taken as the project baseline. This baseline yield has been predicted to reduce in accordance with the GasSim model. This method approach is due to the difficulties in extracting gas from old waste below 200m^3/hr without risk of air being drawn into the site. Also, the existing gas wells and pipework infrastructure is largely defunct and based on 10 year old technologies. The yield from the old waste has been assumed to cease by 2013. Bisasar Road landfill will be progressively closed and rehabilitated, with gas wells installed with the completion of each planned phase – in line with the DSW's established "extending green carpet" method. There are currently 43 gas wells at the site, but only 13 are extracting landfill gas. DSW predicts that operations in 2005 will allow the installation of no fewer than 40 new wells. This will give a total of 53 operational wells by project commissioning. Further wells will be provided as waste is disposed and the site is progressively restored from South to North. Some of the phase operations will also see the construction of temporary or sacrificial wells that will be covered by disposal in later years. Wells will be provided at around 50m spacings and given an active site area of some 350,000m^2. It is anticipated that the final wells will be installed by 2016. The site is large enough to accommodate some 130 gas wells.

A yield of 50m^3/hr for a newly constructed well at Bisasar Road has been assumed. However, the gas yield from the wells will decrease exponentially over time and are expected to fall to a yield of about 30m^3/ hr after 20 years. Wells will be maintained and progressively replaced as needed during the project's life. The maximum achievable extraction efficiency of the gas system is assumed to be 80% of the gas produced. The gas utilisation plant is assumed to require 700m^3/hr at around 50% methane to produce 1MW. This is slightly conservative as plants such as the Jenbacher engines require less than Bisasar's gas flow of 700m^3/hr for 1MW of power. There is also the potential for heat recovery from the engine, such as the Turboden Organic Rankine system. Surplus gas from the engines will be "spilled over" to on-line high temperature closed flare units.

Analyses of the Raw Landfill Gas for power generation

Landfill gas constitutes a high value fuel for gas engines with a calorific value of approximately 5kWh/Nm^3 and therefore, can be practically used for the generation of energy (Jenbacher, 2003). The suppliers of gas engines have set limits for various compounds present in LFG that may cause problems during engine operation. Typically these compounds include: Volatile silicones/siloxanes; Halocarbons; Reduced Sulphur Compounds and Nitrogen compounds.

The volatile silicon compounds deposit abrasive silica in the combustion chambers leading to rapid wear and subsequent engine failure (Bogner, Lombard and De Mattos, 2003). The probable source of these compounds is deodorants, cosmetics, haircare products, defoamers, lubricants and to a degree, waste water treatment sludges. The halocarbons contain both chlorine and fluorine and when combusted can generate highly corrosive hydrochloric and hydrofluoric acids. These acids can lead to severe bearing damage and premature failure. The source of these compounds is probably from refrigerants, aerosol propellants, chlorinated solvents and blown foams. Sulphur (S) and nitrogen (N) compounds also generate acids when combusted causing the same problems as the halocarbons. The volatile N and S compounds are generated through the anaerobic breakdown of waste, particularly domestic and food waste.

The problems caused by the volatile compounds can be managed by regular analysis of the lubricating oil. The build-up of Si, N, S and wear metals such as Fe, Pb, Sn, Cr, etc, is monitored and oil is replenished when critical levels are reached. Where volatile compounds are in excess of engine manufacturers specifications they may be removed from the landfill gas by passage through purpose-built filters containing activated carbon and/or iron oxide. Activated carbon is used to remove volatile silicon and halocarbons whilst S compounds can be removed with iron oxide.

Tables 5 through 7 below show the analytical results for landfill gas quality sampled from all three landfills of Bisasar Road, La Mercy and Mariannhill.

Table 5: Site analyses obtain by a GA 94 determined at time of sampling.

Site	*CH_4%*	*CO_2%*	*O_2%*	*Temp °C*	*Line Press mBar*	*At Press mBar*
Bisasar Rd	44.4	33.6	2.2	41	8.6	1021
Mariannhill	48.4	39.6	0.1	38	10.2	992
La Mercy	60	40	0	25.8	0.7	1010

Table 6: Laboratory analyses showing the results obtained by Landfills Inc (Bogner et al, 2003) using the laboratory of Analytical Solutions (ANSOL) - Major Component Analysis

Total	*Description*	*Methane*	*Carbon dioxide*	*Nitrogen*	*Oxygen*	*GHV, dry (14.73 psi)*		*Remark*
Sample #		(%)	(%)	(%)	(%)	(Btu/Scf)	(MJ/M^3)	
C0902a01a	LFG – Mariannhill (cy0701)	44.0	37.1	18.3	0.60	446	16.63	
C0902a01b	LFG – Mariannhill (sp0701)	43.7	37.0	18.6	0.66	443	16.52	
C0902a02a	LFG –Bisasar Road (cy0702)	41.8	31.1	24.6	2.50	424	15.81	
C0902a02b	LFG –Bisasar Road (sp0702)	5.0	3.9	71.5	19.5	51	1.91	Possible air leak
C0902a03a	LFG – La Mercy (cy0703)	56.3	43.6	0.12	0.01	572	21.30	
C0902a03b	LFG – La Mercy (sp0703)	56.3	43.7	0.01	<0.01	572	21.31	

Note: All concentrations were normalized to 100%. Moisture, ethane and heavier hydrocarbons were excluded in normalization. GHV is calculated based on 4 components

Table 7: Laboratory analyses showing the results obtained by Landfills Inc (Bogner et al, 2003) using the laboratory of Analytical Solutions (ANSOL) - Total Elemental Analysis

Sample #:	*Conc. Unit*	*C0902a01*	*C0902a02*	*C0902a03*
Description:		*LFG – Mariannhill (sp0701)*	*LFG –Bisasar Road (cy0702)*	*LFG – La Mercy (sp0703)*
Total Organic chlorine	ppmv	26	9	9
	mg/M^3	41	14	15
Total Organic fluorine	ppmv	5.9	0.8	3.4
	mg/M^3	5.0	0.7	2.9
Total Organic silicon	ppmv	33	0.2	3.1
	mg/M^3	41	0.2	3.9

Note: Some results were reported with additional significance for reference.

Gas from Bisasar Road Landfill was found to slightly exceed the Jenbacher specification for volatile silicon and an activated carbon absorber may be required. The limitations for volatile halogens and sulphur were not exceeded. Further gas sampling and analysis should be undertaken closer to the time of purchase of engines and a final decision made on whether activated carbon absorption is required. Gas from Mariannhill Landfill exceeds the Jenbacher specification for volatile silicon and an activated carbon absorber will be required. The limitations for volatile halogens and sulphur were not exceeded. It would be recommended that further gas sampling and analysis should be undertaken closer to the time of purchase of engines and a final decision made on whether activated carbon absorption is required. Gas was only taken from two of the landfill cells and the final extraction system on additional cells may yield different gas analysis results.

Gas from La Mercy met all the limitations imposed by the engine manufacturers listed. This site has not been subject to active extraction and further sampling and analysis may be required before any gas engines are installed. Based on the volatile Si content in gas from the other two landfills it would seem likely that an activated carbon absorber will be required.

The Emissions Debate – The Environment with and without the project

A comparison study was carried out by Enviros (UK) for eThekwini-DSW of the emissions to air which would result with and without the proposed landfill gas electricity generation scheme proposed at the Bisasar Road landfill site, eThekwini Municipality, Durban, South Africa. The comparison was carried out by considering the volume of landfill gas which is forecasted to be generated over the twenty-one-year lifetime of the scheme. For purposes of this calculation, a 20-year period was considered. Under the proposed scheme, landfill gas would be collected and burnt in landfill gas engines. A smaller proportion of the gas can be expected to escape collection, and would be released directly to the atmosphere. A proportion of the gas would be flared – typically the 'spill-over' gas that exceeds the flow volume acceptance capabilities of the generation units. If the proposed scheme is not implemented, it has been assumed in this calculation that the majority of the landfill gas would be released directly to the atmosphere, with a small proportion being flared.

Information from the UK, was used to estimate the emissions to air likely to be associated with the two scenarios – "with scheme" and "without scheme." The information was generally taken from research published by the UK Government Department for Environment, Food and Rural Affairs (DoE (UK), May 2004), and compares closely with published literature from actual project results (Gillett et al, 2002; Haigh et al, 2002) and equipment suppliers (Jenbacher, 2005; Hofstetter 2005). Further published research literature utilised for this calculation was obtained from DSW (DSW-Enviros, May 2003), the UK Environment Agency (2004), the UK National Atmospheric Emissions Inventory (2005), and Lindberg et al (2001). This research information allows the amounts of different substances emitted to air associated with the different modes of landfill gas control to be estimated and added together over the lifetime of the scheme.

The substances set out in this calculation do not comprise a complete list of the substances which would be emitted, but do provide a representative cross-section of the substances of greatest potential concern. Four groups of substances are of potential concern: combustion gases (e.g. oxides of nitrogen, sulphur dioxide and hydrogen chloride); volatile organic compounds (e.g. benzene); semi-volatile organic compounds (e.g. dioxins and furans) and trace metals (e.g. arsenic and nickel). Table 8 shows the volumes of gas treated in different ways for the "with project development" and "without project development" scenarios. Table 9 shows the mass emissions of different substances for the "with project development" and "without project development" scenarios. Emissions of substances associated with landfill gas combustion are higher for the "with project development" scenario. Conversely, emissions of substances associated with landfill gas itself are higher for the "without project development" scenario. For the "with project development" scheme, emissions of all released substances have been assessed in detail, and found to comply with relevant air quality standards and guidelines. Some substances (e.g. some of the metals) cannot be assessed in this way, because no information is available on the levels of some components in landfill gas. By installing a landfill gas combustion plant, the collection and control of these components will be improved, and the emissions can be properly measured and assessed. Also, emissions of trace metals from landfill gas engines would be expected to be no higher than emissions without the use of engines, and may well be reduced by the engines because of absorption into the oils and seals within the engine.

Table 8 : Volumes of landfill gas over 20 year lifetime with and without scheme

Determinant	***Without project development***	***With project development***
Total volume of gas generated	1 113 million m3	1 113 million m3
Volume of gas flared	20 million m3	75 million m3
Volume of gas used for electrical generation	0 million m3	601 million m3
Volume of gas released directly to air	1 093 million m3	438 million m3

Table 9 : Mass emissions of air pollutants over 20 year scheme lifetime

Substance	***Total without project development***	***Total with project development***
Nitrogen oxides	10 T	2742 T
Total Particulates	1 T	24 T
Sulphur dioxide	12 T	255 T
Hydrogen chloride	3 T	20 T
Hydrogen fluoride	1 T	14 T
Total VOCs	139 T	55 T
1,1-dichloroethane	15.0 T	5.9 T
Chloroethane	5.6 T	2.2 T
Chloroethene	6.1 T	2.4 T
Chlorobenzene	13.4 T	5.3 T
Tetrachloroethene	18.4 T	7.8 T
Methane	418000 T	170000 T
Arsenic	0.0032 T	0.0048 T
Mercury	0.00802 T	0.00796 T
Dioxins and furans	0.37 gTEQ	0.57 gTEQ
Carbon dioxide	746000 T	1418000 T
Benzene	1.34 T	0.53 T
Global warming potential	9524000 T CO_2 equivalent	4988000 T CO_2 equivalent

Project Tendering of *Component One*

In November 2004, in anticipation of a favourable outcome to eThekwini's rebuttal of the appeal lodged against the record of decision (ROD) of the EIA, tendering processes for "Component One" (which comprises the Mariannhill and La Mercy landfills) was initiated. The project development was split into two contracts for the combined landfill sites of Mariannhill and La Mercy. One project (Contract No. WS 5607) was let for the *Installation of landfill gas extraction wells and flare systems at the La Mercy and Mariannhill Landfill Sites*. This contract comprised the installation of 19 gas wells (12 at La Mercy and 7 at Mariannhill) with interlinking pipework, gas collector mains, and two (2) 1 000 Nm^3/hr high temperature closed-type flare units. The second project (Contract No. WS 5608) was let for the *Supply and Commissioning of Landfill Gas Generators and Equipment at the La Mercy and Mariannhill Landfill Sites*. This contract comprised the installation of two (2 No.) 500 kW type landfill gas spark ignition type generating engines with a requirement to price a third such unit, as well as provision for switchgears, earthing systems, gas 'spill-over' to flare switching systems and full project commissioning. Both contracts incorporated tender items for the pricing of the operating and maintenance of the gas wells, flare systems and electrical gas generators. Tenders were closed by February 2005.

Although the eThekwini Municipality has adjudicated all of the tenders received, they have not as yet awarded the contract to a contractor. Owed to the unexpected protracted EIA processes with component one, eThekwini have requested the tenderers to extend their tender validity periods – the latest extension now extends into November 2005. The lowest tendered price received for the first contract (WS 5607) amounted to some R6.6 million (excluding VAT and escalation). This equates to a unit price per installed gas well, with linking pipes and gas main, and full capacity flaring, of approximately R348 000 per well. This is significantly more expensive that the R250 000 estimated cost, but additional costs have arisen as the engineering costs for the generation compound are included in this tender. The initial establishment of the project, incorporating gas collector mains, also skews the unit costs somewhat.

On the other hand, eThekwini were fairly accurate with their initial estimates for the installation of generation equipment being approximately R2.75 million per installed 500 kW engine (totalling R8.25 million for the three) and some R0.08 (8 cents) per kilowatt hour for operating and maintenance (O&M) costs for a 7 year period or estimated production of some 55,8 million KWh. The lowest tendered price received for the second contract (WS 5608) amounted to some R7.6 million for the provision of, for all intents and purposes, 1.5 MW of generation power. The unit price is, therefore, approximately R2.53 million per 500 kW generation engine. The O&M cost for the 7 year generation period summated to some R3.26 million, which equates to a unit O&M cost of approximately R0.058 (5.8 cents) per kW hour. The latter also has a training component built into the unit price which is in line with the eThekwini-DSW's drive to effect 'home-grown' or internal technical expertise on this CDM project.

THE BROADER WIDTH OF DURBAN'S CDM TECHNICAL EXPERIENCE

The NEPAD Prospective

Africa currently has a single CDM registered project, and albeit that Morocco is rapidly gathering momentum for the introduction of more CDM projects, Asia and South America clearly lead the way in numbers of CDM projects underway. It is anticipated that large-scale emission reduction projects will come from China, set to corner a significant amount of carbon finance monies. The has been, since 2003, approximately US$350 million awaiting injection into African CDM projects, but to date very little to only nothing has been tied up into project agreements. The New Partnership for Africa's Development (NEPAD), which set out a VISION and STRATEGIC FRAMEWORK FOR AFRICA's RENEWAL, offers a most useful instrument to launch CDM projects on the African continent. In fact, through the NEPAD initiative, the City of Durban (eThekwini Municipality) has been approached for their CDM technical assistance to initiate projects in other African states. Two experiences are briefly listed below namely the Hulene Landfill CDM in Maputo, Mozambique, and the Mpererwe Landfill on the outskirts of Kampala, Uganda.

The opportunities presented by the New Partnerships for African Development are significant, both for national governments on the African continent and for individual project developments. The eThekwini Municipality has recently highlighted NEPAD in its "Reviewed Integrated Development Plan (IDP) 2003 – 2007, for the review period 2004 – 2005" as an important contributor to the Municipality's democratisation drive aimed at a desired outcome for "accessible, accountable and aligned local government". The City of Durban, of the eThekwini Municipality, has been selected as one of the seven initial African NEPAD cities, defined as those that are "functional, economically productive, socially inclusive, environmentally sound, safe, healthy and secure" (UN-Habit, 2003). A strategy of the Municipality is to align the NEPAD development framework to its IDP, implying that NEPAD will operate within eThekwini's IDP development roadmap.

The NEPAD strategic framework document arises from a mandate given to the five initiating Heads of State (Algeria, Egypt, Nigeria, Senegal, South Africa) by the Organisation of African Unity (OAU) to develop an integrated socio-economic development framework for Africa. The 37th Summit of the OAU in July 2001 formally adopted the strategic framework document. The aim of NEPAD is to address the current challenges facing the African continent. Issues such as the escalating poverty levels, underdevelopment and the continued marginalisation of Africa are paramount and have needed a new radical intervention. NEPAD projects are spearheaded by African leaders, to develop a new Vision that would guarantee Africa's Renewal. NEPAD is somewhat an operational tool of the established African Union (the AU) that will allow the full depth of a country's resource base, be it expertise, materials, products, services, infrastructural advice, and so forth, to affect an impact on the development of African countries. Importantly, is that NEPAD is 'by Africans for Africans' and development objectives will serve the direct needs of a country within the country's framework constraints of achieving sustainable development. In this way, the public sector or specifically the metropolitan cities of South Africa, offer significant opportunities to NEPAD and the sharing of technical expertise and experience. Whilst at present the NEPAD links and projects through Durban to Africa are very few, it is indeed a distinct possibility that CDM projects will promulgate NEPAD initiatives in the near-term future – and vice-versa.

The Hulene Landfill – Maputo, Mozambique

At the behest of the PCF-World Bank, the Head of DSW and the CDM project manager for the Durban landfill gas project visited Maputo during late 2004. The purpose of the visit was to make personal contact with the City of Maputo at Deputy-Mayoral level, and to interface with Maputo's solid waste management team. Maputo currently operates one disposal site, namely the Hulene Landfill, with another some distance away in another district. The planning for the development of revised waste management practices, legislation and a new engineered landfill facility is well underway with international consultants working with Maputo's solid waste officials.

During the visit to Maputo, the DSW team inspected the Hulene Landfill with the prospect of providing assistance, through a NEPAD initiative, to develop a CDM project at this site. The participation and cooperation with the Maputo authorities was outstanding and a close bond was immediate. A definite test to NEPAD is that the transfer of experience and expertise is so often translated to the actual working together of key individuals who strike up a working relationship and friendship. But, difficulties arise when these persons are tied to the arduous responsibilities that confront them daily in their own jobs back home! Nonetheless, the Hulene landfill, albeit better described at present as waste disposal 'dump', does offer CDM project potential. It is estimated that there is close to one million cubic metres of waste disposed of in this site, of which the organic and readily biodegradable fraction of the waste is some 65~70%. Provisional investigation findings and feasibility calculations were completed by DSW for the PCF in hope of a future project. But, it is widely known that for the level of sophisticated equipment that must be installed for a landfill gas extraction project, the site itself must mirror the same standards of operational sophistication. This is required to offer appropriate and safe working conditions for the gas extraction equipment. Hulene-Maputo requires much operational effort to attain this standard – but may do so through an established partnership with her NEPAD partner, Durban.

The Mpererwe Landfill – Kampala, Uganda

The City of Kampala, through Uganda's National Environmental Management Agency (NEMA) and the Kampala City Council (KCC), are wishing to develop a Clean Development Mechanism (CDM) project with the World Bank's Carbon Finance Business unit, involving the harnessing of landfill methane from Kampala's Sanitary Landfill site. This proposed project is very similar to the eThekwini / World Bank Landfill Gas to Electricity CDM project, albeit that the Kampala project is being fast-tracked through the direct involvement of their National Government. In fact, through such a 'team approach' with their National Government, Kampala was programming to commission this project within 12 months.

Uganda is an important country in the Central-East-Africa Region of the African continent, being key to the door opening onto a growing economy, a vibrant business community and increased tourism to the world's unique and prime sought after wildlife and scenery viewing destinations. Early in the 20^{th} Century, Winston Churchill was struck by the natural beauty of Uganda, and so enthralled was he that he extolled Uganda using the famous words *"Uganda is from end to end one beautiful garden … The Pearl of Africa"*. Uganda is still, unfortunately, lumbered with the burden of being perceived as an unsafe and insecure country. But, this perception is largely derived from the Idi Amin regime that was terminated in April 1979 – 26 years ago! Uganda does have significant border concerns with localised warring factions battling on the Sudan border in the north, and safety concerns in the south western region, on the Rwanda/Congo border. However, Uganda should be encouraged and supported by the international community for its modern times effort that provides safety and security and a population that is kind, friendly and eager to meet visitors to their country. Kampala is stepping up onto the world stage set to become a leading city of Africa, set to offer political and economical stability with its current vision.

The country's ratification of the Kyoto Protocol has indicated Uganda's global concern to the environment and their national responsibility to offer participation in reducing carbon emissions to the atmosphere. Uganda sets out a 'triple bottom line' strategy where the public sector are determined to realise good financial practice with the growing economy, social upliftment (specifically in terms of poverty alleviation) and environmental best practice. With a population of some 23 million, Uganda covers an area of some 242 000 square kms of which 37 000 is open water.

Kiteezi Landfill (Mpererwe Sanitary Landfill)

The Mpererwe Landfill site is the landfill site that is to be adopted for a viable landflll gas utilisation project, being the disposal facility utilised by the City of Kampala. The site is closely bounded by members of the public on all boundaries; however, the dwellings situated within a radius of 20 to 50m from the engineered edge of the waste body, to the west and south of the site are of distinct concern. The steep side-slopes comprising of a geological profile of transported ferricrete type material, albeit intact, may yield to landfill gas migration. It is crucial that these side slopes are appropriately lined to minimise the risk of gas migration, and/or these dwellings are moved.

Dumping at the site started in 1996 and methane production is now very active. During the period of 1996 – 2000 the site was operated as an unmanaged dump. From 2000 to the present day the site has been operated to a degree as an engineered landfill. There is, however, physical evidence of a continuous methane loss in areas of the large peripheral uncovered surfaces some of which are now burning. Approximately 30 gas extraction wells are possible on the site when it is completely filled with waste with the first 10 wells immediately possible. A significant methane resource exists in the existing waste mass, and the peak methane production will occur sometime in the next 4 – 6 years. There are some technical problems and financial issues with the landfill that will continue to inhibit any methane recovery through the wells by the Kampala City Council (KCC) site management/operations contractor without a CDM intervention.

The estimated CH_4 potential for a 10 contract period has been calculated as 42,524 tons CH_4 x 21 = 0.893 million tons CO_2e. The recoverable CH_4 potential for CDM validation is estimated as 0.893 million tons CO2e x .7 baseline factor x .8 collection efficiency = 0.5 million tons CO_2e with an average annual capture of 50,000 tons CO_2e.

The Potential ER Value: The total 10-year ER potential for the Kiteezi site (Mpererwe Landfill) is 0.5 million tons CO_2e. The World Bank contractual consideration is 0.5 million tons CO_2e. Assuming a purchase price of US$5.00 per ton CO_2e, the contract value is US$2.5 million.

The Kahrizak Landfill – Tehran, Iran

In recent times, the Islamic Republic of Iran has developed a strong commitment to environmental protection for present and future generations (UNDP/DoE Iran, 2003). Iran has played a key role in the international community with the issue of combating climate change and developed a comprehensive inventory on Green House Gas emissions. Such environmental commitment has realised a transformation of solid waste management in Iran, and specifically in the capital City of Tehran. A strategy of the Municipality of Tehran is to develop sanitary landfills where landfill gas and leachate emissions are appropriately controlled and managed. It is anticipated that landfill gas methane is to be utilised for energy recovery, an attempt is to be made to change landfill sites from anaerobic to semi-aerobic sites to reduce methane emissions and improve leachate quality, and waste minimisation and source separation technologies are to be intensified. This strategy, however, is a significant *about face* for Tehran, which has a population of some 8.5 million rising to some 10.5 million during any typical day. Tehran currently disposes of some 7,000 tons per day on the largely non-engineered Kahrizak landfill facility. A waste management strategy, and with particular regard to this paper, a *landfill management strategy* has required deliberate and coordinated steps where engineering and economic responsibilities are being systematically implemented by Tehran.

In recent times, the Tehran Solid Waste Management Organisation (TSWMO) has coordinated with the World Bank to institute a closure strategy for the Kahrizak landfill, and commission a new sanitary landfill facility in the Housang district. This paper provides an overview of the planning for this proposed undertaking, yet provides detail on the closure plan for the Kahrizak landfill. The Kahrizak site covers a waste footprint of some 500 hectares, of average waste depths of 25m, containing municipal solid wastes from the 22 districts of Tehran with a biodegradable fraction of some 68% comprising “wet waste: food, fruit, peels, etc” (OWRC; 2004). The landfill area is layered with wastes of varying age and stage of decomposition. Also, historical disposal practice, that employed large (up to 30m deep) trenching type excavations, has left several vertical banks in the waste mass of soil material. The site also contains various hazard wastes, predominantly untreated health care type wastes.

Owed to limited accuracy on gas yields, and the extremity of the site area, a landfill gas collection system for Kahrizak, requires sound investigation as opposed to expensive *suck it and see* methods. The collection of the landfill gas, with the objective of *tapping into* the carbon asset where global emission reductions can be realised and carbon finance obtained, presents considerable opportunities to Tehran. However, its safe, successful utilization requires a great deal of planning and preparation (Robert Eden; 2002).

Ahead of planned gas pumping trials, three landfill gas generation models have been used to determine a sustainable gas yield from the landfill over a time scale of some 10 years viz. the LandGEM method 2E, the Enviros (UK) model and the GasSim (Environment Agency (EU); 2002). The GasSim model’s assumptions have shown to be more appropriate to Kahrizak’s gas generation potential, which has been calculated, for the purpose of carbon finance deal through a CDM (Clean Development Mechanism) project, at some 6 million tons of carbon dioxide equivalents. The calculations and engineering assumptions are provided in this paper. It is anticipated that, following the gas pumping trials in early 2005, the full scale gas extraction project will be commissioned for Kahrizak. The main objective of the landfill gas pumping trials is generally to ensure that the design under consideration is of the correct order of magnitude in terms of capacity and thus provides confirmation of the computer simulations carried out prior. Whilst expected gas quality has been largely established for Kahrizak, the defining of the probable landfill gas production rates per well installation, exact abstraction pressures and the radii of zones of influence (or cone of influence) being effected by individual extraction wells is largely *hit-and-miss*. This paper describes methods that have been planned for Kahrizak to ensure that appropriate, yet economical solutions are applied to Kahrizak, and the 500 hectare potential is maximised. The paper aims to offer the reader science that can be useful to overt *hit-and-miss* technology – particularly for projects like CDM's where gas deliverables must be within acceptable orders of accuracy.

Figure 1: The Kahrizak Landfill Site showing a width section of some 3,0 km of this 500 hectare facility. Average waste depth is some 25m. The planned gas collection project is to maximise the harnessing of landfill methane from the entire site.

Iran has played a key role in the international community, for example at Conference of the Parties (COP) VI in The Hague in November 2000, Iran was prominent with the issue of combating climate change and has developed a comprehensive inventory on Green House Gas emissions. Such environmental commitment has realised a transformation of solid waste management in Iran, and specifically, in the capital City of Tehran. A strategy of the Municipality of Tehran is to develop sanitary landfills where landfill gas and leachate emissions are appropriately controlled and managed. It is anticipated that landfill gas methane is to be utilised for energy recovery, an attempt is made to be made to change landfill sites from anaerobic to semi-aerobic sites to reduce methane emissions and improve leachate quality, and waste minimisation and source separation technologies are to be intensified. A waste management strategy, however, and with particular regard to a *landfill management strategy* wherein the closure of the Kahrizak Landfill facility and gas extraction from this site is envisaged, will require deliberate and coordinated steps where engineering and economic responsibilities are systematically implemented by Tehran Municipality. The Tehran Solid Waste Management Organisation (TSWMO) has, over the last two years, coordinated with the World Bank to institute a closure strategy for the Kahrizak landfill, and commission a new sanitary landfill facility in the Houshang Abad district.

Owed to limited consistency on accuracy of potential gas yields from landfills, and the extremity of the site area at Kahrizak, a landfill gas collection system for the site requires sound investigation as opposed to expensive full scale *suck it and see* methods. The collection of the landfill gas, with the objective of *tapping into* the carbon asset where global emission reductions can be realised and carbon finance obtained, presents considerable opportunities to Tehran. However, its safe, successful utilization requires a great deal of planning and preparation (Robert Eden; 2002).

Ahead of planned gas pumping trials, three landfill gas generation models have been applied to determine a possible sustainable gas yield from the landfill over a time scale of some 10 years viz. the LandGEM method 2E, the Enviros (UK) model and the GasSim (Environment Agency (EU); 2002). The GasSim model's assumptions have shown to be more appropriate to Kahrizak's gas generation potential, which has been calculated, for the purpose of carbon finance deal through a CDM (Clean Development Mechanism) project, at some 6 million tons of carbon dioxide equivalents. It is anticipated that, following the gas pumping trials in early 2005, the full scale gas extraction project will be commissioned for Kahrizak. The main objective of the landfill gas pumping trials is generally to ensure that the design under consideration is of the correct order of magnitude in terms of capacity and thus provides confirmation of the computer simulations carried out prior.

1.0 Background

1.1 Country Background. Iran is an important country in the Middle East Region. With a population of 63 million, it is the most populous country in the region, and the 16th most populous in the world. With a GDP of US$ 111 billion, Iran is the second largest economy in the region. It is also the second largest OPEC oil producer and has the world's second largest reserves of gas. Iran is progressively emerging from a long period of uncertainty and instability, marked of by the destructive war with Iraq, internal post-revolutionary strife, international isolation, and deep economic instability. As an ancient civilization, and an internationally important cultural pole, it exerts a great deal of influence not only in the region but also in the world. Iran's economic prosperity, social progress, and greater integration into the world economy will not only bring benefits for the Iranian population but will also have important spill-over effects for the region. The people Iran, as noted by persons visiting on the World Bank Missions, are extremely kind, generous and eager to interrelate with international perspectives. In fact, the visiting landfill gas specialist's first Farsi words were *shormar hasti geli meghrabhan, tash akor* meaning *you are extremely kind, thank you* (Strachan, 2004).

2.2.2 Information on the characteristics of the landfilled wastes. The wastestream to Kahrizak comprises 3 main waste types viz: MSW, Industrial Waste and Hospital Waste (HCW – Health Care Waste). Fortunately waste characterization studies have been carried out and can be reported for utilization for the modeling of landfill gas production rates. The table below represents wastes that are typically transported to the site from the transfer stations of Tehran.

Table 1: Waste characteristics of the Kahrizak landfill waste body

Waste Type	***Mass %***	***Volume %***
wet waste	67.8	26.4
bread	1.0	2.7
soft plastic	2.2	14.8
hard plastic	0.6	4.0
PET	0.7	9.7
Plastic bags	6.2	16.8
Paper	4.4	4.0
Cardboard	3.7	5.1
Ferrous metals	1.6	1.1
Non-ferrous metals	0.2	0.1
Fabric	3.4	9.4
Glass	2.4	2.2
Wood	1.7	1.5
Tyres	0.7	0.6
Leather	0.6	0.4
Dust & Rubble	1.3	0.6
Special Waste (Health Care Waste)	1.6	0.7

Note: 'Wet waste' comprises food waste, peels, meats, etc – all typically biodegradable wastes.

Waste Volumes & Disposal Rates: Approximately 2, 0 million tons of waste pa is delivered to the site. Daily waste tonnages average at 5 500 tons per day, with days of the week rising to 7 000 tons in one day. The landfill 'in place' volume of an 'Area A' (refer to the Annexure 2 sketch) is some 8.10 million cubic metres, and an 'Area B' of some 12.66 cubic metres. Hence, it is anticipated that the total 'in-place' waste volume from where a sustainable yield of landfill gas could practically be extracted is some 20.8 million cubic metres. This must be verified by the appointed contractor.

Waste Areas and Depths: Area 'A' (also referred to as the Hussein Abad area) is approximately 55 hectare in size and waste depths range from 10m to 50m. The area was landfilled according to a 'trenching method' where large excavations, hundreds of metres in length, 20 to 25m in depth, some 50m in width, spaced approximately 30m apart, were carried out. Hence, there would be some 'dead ground' in between the excavations. BUT, later a layer of waste was placed over the entire area of approximately 10m in depth. This would indicate a total depth of some 35m, albeit that several areas were excavated deeper to provide waste depths of up to 50m. The local topography of the landfill appears moon-like with sudden high areas and large canyon-like chases across this area. An average depth of 30m would be a good assumption. The landfill gas in this area smells typical of landfill gas from MSW type landfills and tests with a GA94 instrument showed levels of methane of up to 47%. For area 'B', much the same as that of area 'A' applies, but the stage of methanogenesis is questionable. It was difficult to pick up a scent of landfill gas, and the smell was more of a blend of phenols and a sweet mangos rotten odour – arguably typical of young acetogenic type landfilled wastes. But, this may only apply to a newly placed landfill layer and wastes below could yield high volumes of methane. The area of area 'B' is approximately 65 hectare. Also, it is evident from excavations into the waste body that significant burning has taken place in this area for a waste depth of no less than 5m. It would appear from various site investigations, including the recent inspection by Lindsay Strachan, that it would be practical and economically feasible to extract landfill gas from areas 'A' and 'B'. Details of the test pits logged by Strachan (October, 2004) can be obtained from the OWRC. Also, it is noted that waste disposal operations may be terminated on this site by December 2006, although this would not appear to be practically possible as a new-generation-type, lined landfill would require at least 18 months to develop. Hence, the modeling of landfill gas from Kahrizak landfill should extend waste disposal operations to at least the end of 2007.

The Bukit Tagar Landfill – Kuala Lumpur, Malaysia

The KEB Enviro Consortium would plan, register and develop a CDM project, and will tender for potential buyers of the CER credits, from the beginning of 2006 through 2012 corresponding to the end of the first CDM commitment period. It would seem feasible that the project period would be extended through CER purchases beyond 2012 for a possible extension of 3 years for a 10 year total contract period, with buyer links through the EU's linking directive, possible purchase by the World Bank's PCF (prototype carbon fund), etc.

The project registration processes could be performed by local Malaysian expertise, for example by Eco-Ideal Consulting Sdn.Bhd. (representative namely Mr Soon Hun Yang), with project technical assistance and CDM project development experience input from South African professionals (representative namely Mr Lindsay Strachan – Landfill Gas project and CDM specialist). A landfill gas CDM project is currently planned elsewhere in Malaysia and it is reported that this project has received the DNA's (Designated National Authority's) letter of approval (LoA).

The CER price will depend on best option or structured pricing arrangement obtained through a tender process by KEB. Anticipated CER pricings, upon which provisional project financials could be based may vary from US$5.00 to Euro 8.00 per ton CO_2e through 2012. A defined portion to go toward a mutually agreed social development activities that would contribute towards the Sustainable Development criteria of Kuala Lumpur, Klang Valley or Batang Berjuntai.

The site is owned and operated by the Kub-Berjaya Enviro consortium and the current waste-stream originates from the City of Kuala Lumpur (KL), the client of KEB being the Solid Waste Dept. of the City Council of KL. It would appear plausible to assume that, owed to its responsibility to offer final disposal treatment and final accountability for the landfilled wastes at Bukit Tagar, that the right to exploit the landfill gas is vested in KEB. Further to this, the assumption that KEB would be responsible for the "treatment" of the landfill gaseous emissions, to provide site safety, odour control, and so forth, that the right to utilize the gas as a resource is firmly the right of KEB.

The Bukit Tagar Landfill is to crucially offer "available landfill airspace" to replace the existing near-full landfill facility of Puchong. Disposal at the Bukit Tagar facility commenced in April 2005 in an engineered landfill cell, engineered to world leading standards, at a disposal rate of some 1,500 tons per day. The landfill is to be developed in phases over a total "waste foot-print" of 260 ha, planned to hold some 120 million m_3 of MSW (Municipal Solid Waste) over an operational life of some 40 years. The peak waste-stream is anticipated tto be some 5,500 tons per day.

Landfill Gas Generation and Viable CER Delivery Schedule for Bukit Tagar Landfill (Malaysia)

Year	Tonnage MSW Disposed in year	Total Tonnage Disposed at Bukit Tagar	Est. CH_4 produced	Est. CER (CO_2 eq)	Total Cumulative Est CER
2005	500 000	500 000	No project installed	No project installed	No project installed
2006	650 000	1 150 000	3 540	74 340	74 340
2007	760 000	1 910 000	5 880	123 440	197 780
2008	990 000	2 900 000	8 930	187 530	385 310
2009	1 100 000	4 000 000	12 320	258 720	644 030
2010	1 300 000	5 300 000	16 325	342 825	986 855
2011	1 500 000	6 800 000	20 950	439 950	1 426 805
2012	1 800 000	8 600 000	26 500	556 500	1 983 305

The estimated CH_4 potential for a 10 contract period can be calculated as some 2.5 million tons CO_2e.
The recoverable CH_4 potential for CDM validation is estimated as 2.5 million tons CO2e x .9 baseline factor x .8 collection efficiency = 1.8 million tons CO_2e with an average annual capture of 180,000 tons CO_2e.

Potential CER Value: The total 10-year CER potential for the Bukit Tagar Landfill is 1.8 million tons CO_2e. The contractual consideration is 1.8 million tons CO_2e. At a purchase price of say US$8.00 per ton CO_2e, the contract value is US$14.4 million or RM$53.28 million.

CONCLUSIONS

Climate change is real and is caused by the increase in the atmospheric concentration of so-called greenhouse gases (GHG's). The human contribution to climate change or *anthropogenic climate change* by the disposal of wastes in landfill sites is significant, for example in the case of Durban (South Africa), in excess of 25% of the City's greenhouse gas emissions are attributed to landfill sites. However, the high methane volume component of landfill gas offers a current resource of *green power* to South Africa. It is planned that the country's renewable energy target will be supplemented by some 6% of landfill gas. Typically, the utilization of landfill gas is not economically viable as the cost of electrical power is distinctly cheap (albeit that the authors avoid the argument of "how cheap" is the "environmental cost"). The Durban landfill gas utilization project, comprising three landfill sites, will cost some R0.25 per kWh (25 SA Rand cents: approximately US$0.04/kWh), whilst the general electrical power sale price (back to the Municipal grid) is some R0.13 per kWh. Effectively, there is a shortfall to project viability of 100%. The injection of the carbon finance, derived from a CDM project undertaking, is just sufficient to allow this project to be viable. However, it is essential to realize, particularly by the general public, that this CDM project is not economically highly profitable. The CDM project is a result of the Kyoto Protocol's mechanisms where the realization of emission reductions in GHG's and sustainable development criteria are paramount only – not financial profits. In fact, with sufficient allowances for ongoing research and development, social benefits, insurances, operating and maintenance, etc, the financial result of the Durban CDM project produces a very low IRR%. For all intents and purposes, the nett project cost equals the project payment allowable.

The Durban Landfill gas CDM project process commenced in early 2002 and was the subject of a discussion even at the WSSD Summit, in Johannesburg in 2002. From a technical standpoint, the eThekwini Municipality's team was ready for project development by the end of 2003. But, an Environmental Impact Assessment (EIA) process that was subjected to single appeals on the Bisasar and the Mariannhill project components has stalled the project. Whilst the bumbling legal and procedural processes of the EIA process can be justifiably blamed for the retardation of this project, the authors lay emphasis on a problem of project prioritization at both Provincial and National level. The South African presidency ratified the Kyoto Protocol that was adopted on 11th December 1997 and was subsequently established as a legitimate host country for the commissioning of CDM projects with the launching of SA's Designated National Authority (DNA) on 1st December 2004. Russia's signing of the Protocol on 16th February 2005 finally brought the commitments of the signing parties of Kyoto into full effect. It would, therefore, seem prudent, that with the seriousness of the Kyoto Protocol, climate change and the realization of emission reductions, there would be prioritization shown by the regulation authorities towards the development of CDM projects in South Africa. Furthermore, it would indeed be advantageous to the development of CDM projects for there to be an increase in demand pressure from a National level. A CDM project should preferably be given prioritization to limit the administration time behind the environmental acceptance process. Also, and most importantly, public awareness on renewable energy, climate change combating and CDM type projects should not be left solely to the project proponent. The "broader picture" on the Durban project was unfortunately obscured by the immediate focus on the landfill operations as opposed to the present (and unseen) GHG emissions from the landfill.

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