LANDFILL GAS RECOVERY IN SOUTH AFRICA: STATUS, ISSUES, AND MARKETS

Jean E. Bogner[1] and Catherine A. Lee[2]

[1]Landfills +, Inc., 1144 N. President St., Wheaton, Illinois
landfill@ameritech.net; also University of Illinois, Chicago.

[2]Lee International, 200 Main St., Westbrook, Maine
cathy@go-worldlee.com

ABSTRACT

Methane (CH_4) is an important greenhouse gas: the total positive climate forcing attributed to atmospheric methane over the last 150 years is 40% that of carbon dioxide. Landfill methane can be used to provide an important local source of energy for industrial heating, electrical generation, or upgrading to a substitute natural gas. Many countries are targeting reductions in landfill methane emissions to achieve greenhouse gas reduction goals. Currently, a window of opportunity exists in South Africa for developing landfill methane recovery projects using carbon credits trading mechanisms. Estimated landfill methane emissions from South Africa are approximately 0.2-0.4 Tg/year. Historically, there have been only a few projects in South Africa among the >1100 commercial projects worldwide since 1975.

This paper outlines the opportunity created by the Kyoto Protocol and addresses technical, non-technical, and market factors pertinent to landfill gas recovery in South Africa. The most important technical issues include predicting recoverable gas at sites with large inputs of commercial and industrial waste, assessing need for remedial engineering measures prior to implementing gas recovery, gas quality considerations, and optimum gas capture concurrent with landfilling operations. The important non-technical considerations include South Africa's regulatory framework, structuring a project to meet market expectations, evolving changes of S. Africa's electrical markets, and historical dependence on a coal-based energy supply. With respect to market opportunities, here we focus on minimizing risk and promoting investment through the sale of carbon credits via the Kyoto-approved Clean Development Mechanism (CDM). The CDM allows developed countries to meet their emission reduction requirements through the purchase of carbon credits from CDM projects in developing countries. A landfill gas project in eThekwini [formerly Durban], which entered into a contract in 2004 to sell carbon credits to the World Bank Prototype Carbon Fund (PCF), has recently raised the visibility and illustrated the viability of S. African landfill methane CDM projects.

BACKGROUND

Methane (CH_4) is the second most important greenhouse gas after carbon dioxide (CO_2). While the major source of carbon dioxide is the burning of fossil fuels, there are many sources of atmospheric methane. These include landfills, ruminant animals, natural gas and coalbed leakages, rice production, biomass burning, termites, wastewater treatment, and natural wetlands, the largest single source (Matthews, 2000). The annual atmospheric input from all sources is approximately 500-600 Tg CH_4 yr^{-1}. [1 Tg = 10^{12} g] Methane has a global warming potential (GWP) that is 23 times that of carbon dioxide (molar basis, 100 yr timeframe), and the total positive climate forcing attributed to methane over the last 150 years is 40% that of carbon dioxide (Hansen et al., 1998). In addition, methane has a short atmospheric lifetime of about 12 years, so that significant reductions in individual sources can begin to reduce atmospheric concentrations within a decade. The methane generated in landfills under anaerobic conditions is the end product of a series of complex decomposition reactions mediated by several groups of microorganisms: hydrolytic and fermentative microorganisms, acidogens, acetogens, and methanogens. Landfill gas contains approximately 50-60% (v/v) methane with the remainder primarily carbon dioxide. In addition, landfill gas contains >200 trace components. By convention, landfill carbon dioxide is not "counted" by the Intergovernmental Panel on Climate Change (IPCC) for global emissions since it is biologically produced, and much of the carbon dioxide emitted from landfill surfaces can be rapidly recycled by plant photosynthetic processes. As recovered, landfill gas can also contain small percentages of nitrogen and oxygen resulting from air intrusion into the collection system.

What is the landfill gas potential for South Africa? A starting point is given in Table 1. Table 1 gives estimated 1990 methane and carbon dioxide emissions for South Africa (Dept. of Environmental Affairs and Tourism [DEAT], 2004) indicating approximately 0.38 Tg of methane emissions from waste. This translates to approximately 532 million m^3 methane, assuming 1 atm. and 0^o C. If contained in landfill gas with approximately 50% (v/v) methane, this equates to over 1 billion m^3 landfill gas. Given that 1) the 1997 estimates from DWAF (Dept. of Water Affairs and Forestry) for annual solid waste production in South Africa are approximately 52 million tons (10^3 kg) of non-hazardous municipal waste; and 2) the fact that 400 waste disposal site permits have been issued for approximately 52% of the general domestic refuse sites since the promulgation of section 20 of Environment Conservation Act 73 in 1989, this estimate is likely to be lower than reality. For example, if estimated annual emissions of about 0.4 Tg are divided by the Strachan et al. (2003) figures for the average 2004 methane production by the three eThekwini [formerly Durban] sites in order to roughly estimate the number of sites producing the national emissions, this would indicate only about 170 landfills actively producing gas. Thus, it seems feasible that the available energy resource may be greater than 0.4 Tg.

Table 1. Estimated carbon dioxide and methane emissions from South Africa in 1990 (DEAT, 2004). Units = kilotons (10^9g). Not included is the third most important greenhouse gas, nitrous oxide (N_2O), estimated at 78 kilotons for 1990, including 61 kilotons of the total from agriculture.

Source	Carbon Dioxide	Methane
A. Energy	238 554	751
B. Transportation	31 390	39
C. Industry	23 461	4
D. Agriculture	-20 614	1 064
E. Waste		380 *(or 0.38 Tg)*

Notes:
A. Includes electricity, industrial, domestic, mining, refining.
B. Includes all transportation.
C. All industrial processes except energy production.
D. All agriculture, forestry, and land use change. The negative CO_2 value for agriculture, land use and forestry represents carbon sequestration by plantations and woodlands.
E. All waste including landfills and sewage/effluent treatment.

Figure 1 shows some additional annual IPCC scenarios for estimated methane emissions using the methodology in Bogner and Matthews, 2003. Several IPCC scenarios were run with various assumptions as shown in the figure. In addition, linear regressions using the “Base” IPCC estimates were used to project emissions to 2004. As described in the figure caption, the three paired estimates use slightly different assumptions with and without 10% methane oxidation. The MCF (methane correction factor) represents the fraction of landfilled solid waste that is expected to degrade anaerobically and produce methane. The MCF of 0.6 (highest “Base” estimate) is intermediate between the MCF used for highly developed countries (1.0) and the MCF for less developed countries in Africa (0.4). The dissimilated organic carbon of 0.77 was used in the original Bingemer and Crutzen (1987) estimate while 0.50 is based on a literature review of the carbon balance in optimized anaerobic landfill systems (Bogner, 1992). If we use a linear regression to project the highest pair of estimates in this figure to 2004, current annual landfill methane emissions from South Africa would be approximately 0.35-0.38, or in the same range as the 1990 DEAT estimates. If we did similar linear regressions from the lower “Base2” and “Base3” estimates in Figure 1, the lower bounding value would be about 0.2 Tg methane yr^{-1}. Thus the entire range for landfill methane potential using IPCC estimation methods would range between approximately 0.2 and 0.4 Tg methane yr^{-1}.

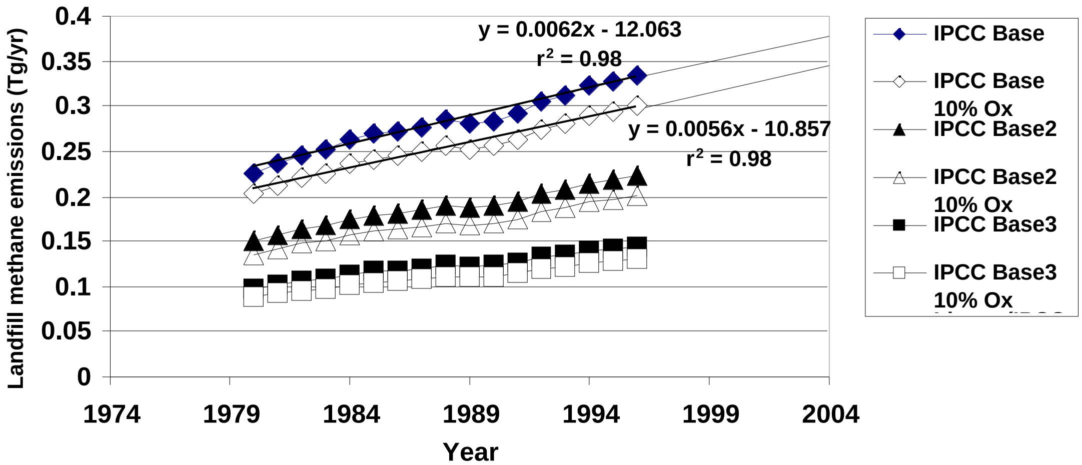

Figure 1. Some IPCC Scenarios for Historic Landfill Methane Emissions from South Africa. [See Bogner and Matthews, 2003 for methodology]. The 2004 emissions were projected from linear regressions based on the 1980-1996 estimates. The "10% ox" refers to an assumed methanotrophic methane oxidation of 10%.

Assumptions:

Base assumes MCF(methane correction factor) = 0.6, and dissimilated organic carbon = 0.77.
Base2 assumes MCF= 0.4 and dissimilated organic carbon = 0.77.
Base3 assumes MCF= 0.4, and dissimilated organic carbon = 0.50.

LANDFILL METHANE RECOVERY IN SOUTH AFRICA: TECHNICAL ISSUES

There are many technical issues to be addressed for the successful exploitation of the landfill methane resource in South Africa (Bogner et al., 2004). As in other countries, each landfill methane project is site-specific with unique aspects not likely to be duplicated in another project. A key issue is the involvement of potential gas users from the earliest conceptual planning stage. Negotiations with potential users and among the multiple parties involved in a project should begin before gas recovery is initiated. In that way, gas quantity and quality requirements are known early in the project.

Uses for landfill gas include direct use in an existing boiler for industrial or commercial heating; onsite generation of electricity; and upgrading to pipeline quality gas, compressed natural gas (CNG), or liquified natural gas (LNG). Typically, use in an existing gas-fired boiler involves only dehydration and compression and is the least expensive option suitable for a wide range of potential gas flow rates. One issue for South Africa is that coal has been historically used for industrial and commercial energy needs. Thus there are few existing gas-fired boilers, and potential new users with industrial or commercial heating requirements might be more receptive to landfill gas than existing users. The capital cost is also generally higher for a gas-fired boiler compared to one that is coal-fired.

Onsite generation of electricity, either for local use or sale to a municipal or national grid, requires a higher capital investment than piping gas to a boiler, but this option may be more attractive where there is no existing user adjacent to the site. It is also generally acknowledged that some parts of South Africa (KwaZulu-Natal, for example) already require, and others will soon require, additional electrical capacity that could be assisted by landfill methane projects. South Africa has a single, government-owned electric utility called Eskom. This national utility generates and distributes power throughout the country although their services are locally supplemented by a number of municipal utilities. However, national policy as well as national and provincial regulations pertaining to renewable energy and the production and distribution of electricity are currently undergoing significant structural changes; thus, new opportunities are quite likely to emerge.

A third option, and the most expensive, is upgrading of landfill gas to pipeline quality. This option involves removal of carbon dioxide and trace components using solid adsorption, liquid absorption, or membrane processes. In this case, the cleaned-up landfill gas competes directly in natural gas markets. The widespread distribution and use of natural gas are just beginning in South Africa; for example, a new large diameter high pressure distribution pipeline from Mozambique is under construction. Historically, SASOL has gasified inexpensive South African coal. Thus, the existing infrastructure for gas distribution is highly variable and does not serve all parts of the country.

There are several other technical issues specific to South African landfill gas recovery projects. First, the warm climate can promote high rates of methane generation, but seasonally dry cover soils can promote high emission rates with low rates of methanotrophic methane oxidation. Thus, methane balance determinations need to be made on representative cells to better understand the relative dynamics of methane generation, emissions, and oxidation under South African conditions which range from warm, semi-arid interior conditions to coastal semi-tropical climates. Morris and Fourie (2004) have recently discussed how low precipitation rates in the semi-arid interior may reduce gas generation rates, while dessication cracking of cover soils may promote direct emissions of unoxidized methane. Secondly, there are waste composition issues—it is important to know the source and types of waste in order to realistically model gas generation. In South Africa, the waste composition differs drastically between affluent and lower income households—for example, Shamrock (1998) examined waste composition from Benoni, an affluent area, which contained 46% putresibles and 25% paper; in contrast, the waste from Wattville, a low income area, was ash-dominated (>50% of total mass) and contained only 18% putresibles and 4% paper. Another waste composition issue is the co-disposal of hazardous waste at many sites. Large inputs of hazardous waste can suppress microbial decomposition reactions, and high concentrations of hazardous volatile organic and organo-metallic components can reduce gas quality. We have recently completed a pre-feasibility assessment of 14 South African landfills. This included preliminary modeling of gas potential with highly conservative assumptions at a number of the sites due to their low inputs of household waste and high inputs of hazardous waste; in addition, the origin of household waste (affluent or low income) was taken into consideration. Third, there will be engineering challenges at some sites where: 1) remedial engineering measures (regrading, cover) need to be implemented before gas recovery can be developed; 2) high leachate levels exist due to historic acceptance of large volumes of liquid waste; and 3) horizontal gas collection systems would be indicated (for example, at a mounded fill with a permitted vertical expansion), but there is no experience to date with horizontal systems. Finally, there is a general need to further develop and expand South African expertise for commercial landfill gas recovery projects (including engineering, analytical, monitoring and modeling). One of us (J. Bogner) got involved in the gas quality analysis for the eThekwini [formerly Durban] CDM project because specialized analytical capabilities were not immediately available in South Africa. A strong recommendation is to develop a landfill gas working group through the South African Institute of Waste Management as a basis for cooperation and sharing of non-proprietary information among landfill gas practitioners.

LANDFILL METHANE RECOVERY IN SOUTH AFRICA: NON-TECHNICAL ISSUES, FOCUSING ON KYOTO REQUIREMENTS

The success of South African projects in the emerging global carbon finance market will depend on the development of successful projects that are attractive to both investors and buyers. The critical non-technical issues for South African landfill gas projects (Lee et al., 2004) include the realistic evaluation of potential gas customers and local markets, a rigorous analysis of financial feasibility, clear ownership of gas rights, compliance with pertinent regulatory requirements (including Kyoto requirements), and the implementation of clear multi-party contractual relationships (land owner, landfilling contractor, gas recovery contractor, gas customer, financial partners, consultants). At the present time, in addition to the EU Emissions Trading Scheme, the ratification of the Kyoto Protocol has provided a new stimulus for commercial landfill gas recovery projects in the developing world. Structured properly, landfill gas CDM projects may be viewed as low-hanging fruit for the creation and sale of carbon credits while benefiting local project owners and surrounding communities.

First, we will provide some background on the Kyoto Protocol. In 1982, over 180 countries adopted the United Nations Framework Convention on Climate Change (UNFCC), the legal structure to enable countries to start the process of stabilizing greenhouse gases. The parties to the Climate Change Convention adopted the Kyoto Protocol in 1996. The Protocol establishes a legally binding commitment for 39 developed countries, called Annex I countries, to reduce their GHG emissions by an average of 5.2% below 1990 levels between 2008-2012. For many years, there has been uncertainty about whether the Kyoto Protocol would actually take effect as it can only take effect when at least 55 countries, representing at least 55% of the 1990 greenhouse gas emissions of the Annex I countries, ratify it. With Russia signing the Kyoto Protocol in late 2004, the Kyoto Protocol is scheduled to take effect in February, 2005. South Africa is a signatory and active supporter of the Protocol while the Bush Administration continues to maintain that it will not ratify the Kyoto Protocol in its current form. The Marrakech Accords were adopted in November 2001 to clarify the Kyoto Protocol's rules by outlining the specific steps a project must follow to qualify under the Protocol. The adoption of the Marrakech Accords has had a substantial impact on the form of the contracts used to sell carbon credits and has stimulated the market substantially.

The Protocol allows Annex I countries to meet their emission reduction targets through mechanisms referred to in the Protocol as "flexibility mechanisms". One of the mechanisms, the Clean Development Mechanism (CDM), is the only mechanism under the Protocol that involves developing or Non-Annex I countries and is the subject of this paper. The CDM concept was first proposed in Brazil and provides a means for developing countries to receive foreign investment, have access to resources and technology to assist in development of their economies, and achieve their development goals while reducing greenhouse gas emissions. The CDM has two key goals:

- To assist developing countries that host CDM projects to achieve sustainable development; and
- To provide developed countries with flexibility for achieving their emission reduction targets, by allowing them to access credits from emission reduction projects undertaken in developing countries.

The credits, often referred to as carbon credits, are called Certified Emission Reductions (CERs) under Article 12 of the Protocol. The Protocol recognizes that greenhouse gases mix uniformly in the atmosphere; thus a reduction in greenhouse gas emissions anywhere in the world benefits everyone. Under the Protocol, one (1) ton of CO_2 equivalent is equal to one carbon credit unit [1 ton = 1000 kg]. The Protocol evolved in part from the fact that reducing greenhouse gas emissions in the developing world at an estimated cost of $1-$4($US)/ton of CO_2 equivalent is considerably cheaper than the cost of achieving comparable reductions in developed countries with costs of >$10/ton of CO_2 equivalent. To avoid abuse, the Protocol calls for strict monitoring and oversight of CDM projects, which is conducted by several bodies as discussed below.

The Protocol establishes three bodies to oversee the CDM. They include the Conference of the Parties/Meeting of the Parties (COP/MOP), the Executive Board (EB), and Designated Operational Entities (DOEs). The COP/MOP is the annual meeting of all of the parties to the Kyoto Protocol. In December, 2004, COP 10 was held in Buenos Aires, Argentina. When the Protocol enters into force, the COP/MOP will be referred to simply as the MOP. The COP/MOP meetings are used to address a wide range of issues related to implementation of the Protocol. The Executive Board (EB) was established in 2001 at COP 7. The EB has ten members serving 2-3 year terms who are selected to ensure regional balance. The EB chair through 2004 was from South Africa. The EB meets regularly to address operational issues, accept or reject proposed CDM project methodologies, and continue to refine the CDM rules. The Designated Operational Entities (DOEs) are entities, domestic or international, that are provisionally designated and eventually, if they meet all the necessary standards, formally accredited as DOEs based on the recommendation of the EB. A DOE's function is to validate proposed CDM project activities and to assist in EB registration, verification and certification of emission reductions. Validation of a CDM project is the process of an independent evaluation by a DOE against the requirements of the CDM on the basis of the Project Design Documents. Project Design Documents are described in the table below. Registration is the formal acceptance by the EB of a validated project as a CDM project activity. Registration is a prerequisite for the verification and certification of CERs related to that project activity. Verification is the periodic independent review of the monitored reductions in GHG emissions that have occurred as a result of a registered CDM project activity. Certification is the written acceptance by the DOE that a project activity achieved the reductions in emissions of greenhouse gases as verified. DOEs are accredited to perform these functions in specific sectors, and only in 2004 were the first provisionally designated DOEs formally accredited.

Projects must comply with the requirements of the Protocol as defined by the EB and COP/MOP in order to be eligible as CDM projects. The steps that must be followed are outlined below in Table 2.

Table 2. Steps required to qualify as a CDM project:

Step	Description	Responsibility
Host country approval	Approval at the national level by the Designated National Authority, consistent with domestic laws and political priorities.	Project developer
Project design document (PPD)	Identification of a concept and development of the project design documents such as baseline estimate, additionality, sustainable development contributions, monitoring and verification plan and stakeholders' opinion.	Project developer
Validation	Third party validation of baselines and other details to confirm that emissions reductions as claimed by the project are considered realistic.	DOE (Designated Operational Entity)
Registration	Registration of the project activity with the CDM Executive Board (EB), once the project has received host country approval.	EB on demand of DOE
Financing	Investor providing capital in the form of debt or equity; the investors may or may not be carbon buyers.	Project developer
Implementation	Building, commissioning and initiating operations.	Project developer
Monitoring	During commissioning and further operations, the progress and GHG offsets are to be monitored.	Project developer
Verification	An independent assessment of project performance against the validated design, including the baseline.	DOE
Certification and issuance of CERs	Based on the verification report, the CDM Executive Board certifies and issues CERs (Certified Emission Reductions)	EB

Furthermore, the Protocol requires that each host country designate a national authority for the CDM. The Designated National Authority (DNA) is the legal entity or institution designated by the host country to manage the CDM process, but its responsibilities are relatively narrow. The South African Government has designated the Department of Minerals and Energy (DME) to serve as the DNA.

Given that one of the Protocol's two key goals is to assist developing countries that host CDM projects to achieve sustainable development, a key and early function of the DNA is to develop "sustainability criteria" that will be used by the DNA to judge whether a proposed CDM project will contribute to sustainable development. If such a finding is made, then the project should receive the approval of the host country. This approval is a prerequisite for a CDM project, and investors often wait for the DNA to indicate its support before deciding whether to invest in a particular project. The DNA has adopted sustainability criteria that each proposed CDM project must meet before the South African government will issue a letter of approval, a prerequisite for any South African CDM project. The DNA approval procedure allows a project to request preliminary review and feedback from the DNA at the early stages of project development. This is an opportunity for a project to get preliminary comments which, if negative, can be addressed up front. This should help avoid delays in the formal part of the approval process. The process also requires that validated Project Design Documents be submitted to the DNA before a project will be considered for approval. Upon receipt of Project Design Documents duly validated by a Designated Operational Entity, the DNA will post the documents on its website for public consultation for a period of 30 days. The project will be evaluated by the DNA in accordance with the sustainability criteria and will be either approved or rejected on that basis within 60 days from the date of receipt of the formal request for approval. The process also provides that developers have a right of appeal to the Minister of Minerals and Energy and, if necessary, to the Administrative Courts of South Africa. The sustainability criteria require conformity with the National Environmental Management Act principles of sustainable development, an approved EIA if required by the project activity, a contribution to national economic development and consistency with other Government policies.

Those considering involvement in a CDM project in South Africa should familiarize themselves with these criteria and incorporate their requirements into project planning.

What makes landfill gas recovery an attractive type of CDM project in South Africa at this time? First, a significant component of CDM project eligibility is the requirement of "additionality". Article 12.5 of the Protocol states that it supports only ". . .reductions in emissions that are real, measurable and additional to any that would occur in the absence of the certified project activity". South African environmental laws and regulations for landfilling, namely the Minimum Requirements for Waste Disposal by Landfill, administered by DWAF (Dept. of Water Affairs and Forestry, 1998 Edition), facilitate additionality since they do not require that landfill gas be recovered and flared/utilized. Passive venting to the atmosphere is the *status quo*—the baseline scenario—unless health and safety considerations dictate, on a case-by-case basis, that other measures be taken. As long as DWAF regulations do not require active gas extraction, any landfill gas that is captured and flared or otherwise utilized in a way that prevents its escape into the atmosphere, will constitute a reduction in the baseline scenario of GHG emissions and will meet the test for "*additionality*". The investors and buyers of carbon credits are discovering that landfill gas recovery projects can meet the additionality test, and so there has been a dramatic escalation of interest in these projects. It is no coincidence that 18% of all carbon credits committed in 2003 came from landfill gas recovery projects, and, as of May 2004, landfill gas recovery projects were the second largest supplier of emission reductions worldwide.

Second, the technologies required for landfill gas recovery and utilization are proven and reliable. As noted earlier, over 1100 projects exist worldwide (Willumsen, 2003) as this technology has been fully commercial since 1975.

Third, the Executive Board has approved a number of different methodologies for calculating the baseline scenario and establishing additionality in landfill gas CDM projects. If a new project follows a methodology already approved by the EB, this increases chances for approval by the EB. The municipality of eThekwini [formerly Durban] has contributed to the international market's awareness of South Africa as a prime source of landfill gas CDM projects and has paved the way with the EB (Strachen, et al. 2003). In addition to eThekwini, the EB has approved nine methane gas projects in Brazil, Costa Rica, India, Malaysia and Vietnam. The methodologies of these projects are well worth reviewing by those considering landfill gas projects in South Africa.

A final factor is that the EU and some individual countries have moved ahead with their own mandatory trading schemes independent of the Kyoto Protocol. Effective January 2005, the EU Emissions Trading Scheme (EU ETS) requires over 15,000 sources to reduce their GHG emissions between 2005-2007. The EU Parliament has also adopted a legally binding measure, referred to as The Linking Directive, that allows companies in the EU to achieve their required emission reductions through the purchase of carbon credits from CDM projects in the developing world. Thus South Africa has the potential to establish itself as a prime destination for CDM investments by EU companies, especially with landfill gas recovery projects.

Timing is important as carbon credits markets evolve. At the moment, the Protocol calls for emission reductions from 2008-2012. The status of reductions after 2012 remains unclear, so investors may not invest in a project unless they are confident it will be capable of selling credits during those critical years of 2008-2012. Given the fact that it takes several years to develop a CDM carbon credit project to the point that it is ready and authorized to start delivering emission reductions, the window of opportunity is relatively small.

The market started slowly but has expanded considerably during the past year. By June 2004, worldwide investors had already spent over $260 million buying carbon credits. As of July 2004, there were 97 projects in 27 countries generating 222,375,573 carbon credits. The world's first Carbon Credits Trade Fair took place in Cologne, Germany in June 2004, attracting 700 visitors from 58 countries, and the second fair will take place in May 2005 [also in Cologne]. The demand for carbon credits to date has remained fairly concentrated—Japanese companies were the single largest purchaser buying 41% of the carbon credits sold in 2003-2004. They were followed by the World Bank's Carbon Finance Unit, which is the buyer for most of eThekwini's credits, with the Government of the Netherlands in third place (Lecocq, 2004). These three buyers accounted for almost 90% of the demand in 2003-2004. It is anticipated that Sweden, Finland, Denmark, Austria and Canada will be more active in the future. These countries are buying credits to meet Kyoto targets with the intention of selling or awarding the credits to industries within their borders. The world-wide carbon credits market is expected to expand significantly now that the EU ETS is in effect, and the Kyoto Protocol will come into force in the first quarter of 2005.

Both the buyers and sellers for the majority of transactions from 1996-2000 were from industrialized countries. The emission reductions contracted in developing countries and transition economies rose steadily from 38 percent in 2001 to 60 percent in 2002, 88 percent in 2003 and 93 percent in early 2004. The majority of the emissions reductions in 2003-2004 come from projects in Asia (51% of the total supply). Latin American was second with 27% of the tons CO_2 equivalent supplied. Developed economies were third followed by Eastern Europe. There are a number of landfill gas and other CDM projects in Romania, and when you add the projects in India, Brazil, Indonesia and Chile, these five countries supplied two-thirds of the CDM carbon credits worldwide in 2003-2004 to date. Africa's potential remains essentially untapped.

What does the market want? The potential funders, investors and/or buyers of carbon credits in a CDM project may be governments, private companies, corporations, foundations, and multilateral agencies like the World Bank, which establishes funds in Annex I countries. Investments can include financial contributions, full or partial equity, loans or lease financing, purchasing agreements for CERs, or other creative financing structures now emerging in response to market factors. Of course, the markets seek low risk, low cost, long-term emission reductions. However, there are some specific factors that make projects more attractive to buyers and investors. Strong support from the host country will enhance a project's value and minimize the perception of risk. Both the completed Project Design Documents and Executive Board registration may be requested prior to buyer commitment. A landfill gas project that cannot guarantee at least 250,000 tons of CO2 equivalent over the contract period (which can vary from 7-21 years) is unlikely to attract interest, though investors and buyers have been quite receptive to projects comprised of multiple landfills, especially if they are under common ownership. Gas quality and a reliable gas user are of the utmost importance. Generally, the fewer parties involved, the more interest there will be in a project. Both a poor environmental compliance record by the landfill operator and the perception of community opposition to a project can be risk factors. Of course, an investor or buyer will want to see documentation on emission reductions, assess the seller's financial strength using historical financial statements, and review information on the project participants. Buyers will also expect detailed breakdowns of projected revenues, required investment and the type of financing. Since buyers and investors will engage in a thorough due diligence process, the technology should be proven and operating capability must be previously demonstrated. To date, there is a very small group of experienced and skilled brokers and consultants internationally who can assist projects to find the most appropriate structures, investors and buyers. It is important that any project developer carefully screen prospective team candidates.

In summary, the growing CDM market worldwide is offering opportunities in South Africa. Structured properly, a window of opportunity now exists for the creation and sale of carbon credits from South African landfill gas projects, which can benefit both local project owners and their surrounding communities. The success of South African projects in entering the emerging global carbon credits markets will depend on the development of projects attractive to international investors.

REFERENCES CITED

Bingemer H G & Crutzen P J (1987) The Production of Methane from Solid Wastes, *J. Geophysical Research*, Vol 92(D2), pp 2182-2187.

Bogner J (1992) Anaerobic Burial of Refuse in Landfills: Increased Atmospheric Methane and Implications for Increased Carbon Storage, *Ecological Bulletin,* Vol 42, pp 98-108.

Bogner J Lee CA Chanton J and Spokas K (2004) Reducing Greenhouse Gas Emissions Through Landfill Gas Recovery in South Africa, *Proceedings WASTECON 2004*, October, 2004, Sun City, South Africa.

Bogner J & Matthews E (2003) Global Methane Emissions from Landfills: New Methodology and Annual Estimates 1980-1996, *Global Biogeochemical Cycles*, Vol 17, pp 34-1 to 34-17.

DEAT [Dept. of Environmental Affairs and Tourism, Republic of South Africa] (2004). State of the Environment Report, from unpublished country study report on greenhouse gas emissions [www.environment.gov.za/enviro-info/sote/nsoer/issues/climate/ pressure].

DWAF [Dept. of Water Affairs and Forestry, Republic of South Africa] (1998) *Minimum Requirements for Waste Disposal by Landfill*, Second Edition, 237 p.

Fourie A B and Morris J W F (2004) Measured gas emissions from four landfills in South Africa and some implications for landfill design and methane recovery in semi-arid climates, Waste Management and Research, Vol 22, 440-453.

Hansen J Sato M. Lacis A Ruedy R Tegen I & Mathews E (1998) Climate Forcings in the Industrial Era, *Proceedings National Academy of Sciences [USA]*, Vol 95, pp 12753-12758.

Lee CA Bogner J & Plourde D (2004) Landfill Gas Recovery: South Africa's Low Hanging Fruit for Carbon Credits Trading, *Proceedings WASTECON 2004*, October, 2004, Sun City, South Africa.

Lecocq F (2004) *State and Trends of the Carbon Market 2004,* published by World Bank, Washington, DC, 42 p [http://carbonfinance.org/docs/CarbonMarketStudy2004.pdf].

Matthews E (2000) Wetlands, pp 202-233 in *Atmospheric Methane: Its Role in the Global Environment,* edited by M A K Khalil, Springer-Verlag, New York.

Shamrock, JR (1998) *A Comparative Study of the Decomposition Processes and the Products of Rich and Poor Refuse in South Africa*, MSc [Eng] Thesis, University of the Witwatersrand, Johannesburg, South Africa.

Strachan L Rampersad R Weinand R Moroka K Couth R Beg N & Chronowski R (2003) *Viable Landfill Gas to Electricity Generation Projects through a CDM—A First for Africa*, Proceedings Sardinia '03 Waste Management and Landfill Symposium, published by CISA, University of Cagliari, Sardinia, Italy.

Willumsen H (2003)*Landfill Gas Plants: Number and Types Worldwide*, Proceedings Sardinia '03 Waste Management and Landfill Symposium, published by CISA, University of Cagliari, Sardinia, Italy.