ATLAS OF GHG EMISSION AND ENERGY POTENTIAL
BY WASTE DESTINATION IN BRAZIL
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SUPPORT

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</tr>
<tr>
<td>C</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeter</td>
</tr>
<tr>
<td>CER</td>
<td>Certified Emissions Reductions</td>
</tr>
<tr>
<td>CDM</td>
<td>Clean Development Mechanism</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential (related to carbon dioxide)</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>h</td>
<td>Hour</td>
</tr>
<tr>
<td>ha</td>
<td>Hectare</td>
</tr>
<tr>
<td>HDPE</td>
<td>High-Density Polyethylene</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>kW</td>
<td>Kilowatt</td>
</tr>
<tr>
<td>LFG</td>
<td>Landfill Gas</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>Mg</td>
<td>Megagram. One Mg equals 1 ton (metric ton)</td>
</tr>
<tr>
<td>MGM</td>
<td>MGM Innova</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter</td>
</tr>
<tr>
<td>MMBTU</td>
<td>Millions of British Thermal Units. One MMBTU equals 1,055 GJ</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
</tr>
<tr>
<td>NMOC</td>
<td>Non-Methane Organic Compound</td>
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<tr>
<td>PDD</td>
<td>Project Design Document</td>
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<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
</tr>
<tr>
<td>tCO₂eq.</td>
<td>Tons CO₂ equivalent</td>
</tr>
<tr>
<td>UNFCCC</td>
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<td>USW</td>
<td>Urban Solid Waste</td>
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<td>RDF</td>
<td>Refuse-Derived Fuel</td>
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<td>SWDS</td>
<td>Solid Waste Disposal Site</td>
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Introduction

The project that brought this publication into reality had the purpose of creating the first Brazilian Atlas on Greenhouse Gas (GHG) emissions specifically generated from final disposal sites for urban solid waste, as well as to estimate its energy potential.

The Atlas was a project chosen by the US Environmental Protection Agency (EPA) to be funded by the Landfill Methane Outreach Program, which helps to reduce methane emissions from landfills by encouraging the recovery and beneficial use of Landfill Gas (LFG) as an energy resource. The production of the document was commissioned to MGM Innova, a leading consultancy firm in the GHG reduction market that specializes in low carbon services and solutions.

As a starting point, the document presents updated statistical information on waste generation in Brazil, the kind of final disposal per region and state, the emissions derived from these disposal areas and respective energy potential, as well as an overview of potential opportunities to explore on generation of carbon credits, and case studies related to three waste disposal sites.

The document’s context brings an analysis of the different technologies in place for energy use of biogas, and specific considerations to be taken into account when selecting the most suitable technology according to the particular context of a given project, in order to make it easier to decide which solution is the most appropriate.

In addition to this scope, the document also presents a review of the different programs and incentives used in Brazil for recovery and use of landfill gas, their impact, and potential measures to be taken for this renewable source to achieve a greater participation in the Brazilian energy matrix.

All of this makes the Brazilian Atlas on GHG Emission and Energy Potential for Solid Waste Disposal the first of its kind in Brazil. By presenting updated data and statistics with scientific-based analyses, the Atlas will help to have a better understanding of the dynamics and trends of the carbon market in the solid waste sector, which will surely contribute for new successful initiatives to take place.

Carlos RV Silva Filho
ABRELPE
Executive summary

The primary purpose of this document is to present an overview of GHG emissions at Solid Waste Disposal Sites (SWDS) in Brazil, and identify the potential for the implementation of emission mitigation projects, including the component of energy utilization of the generated biogas.

The purpose of this document is to serve as a reference for everyone who is related to solid waste management and final disposal, and for the different stakeholders; and as an instrument to promote the use of renewable energy sources.

According to the sources consulted during the development of this Atlas, in 2011 approximately 198,000 tons of municipal solid waste (MSW) were produced in Brazil per day, which equals about 62 million tons of MSW per year. Of the total waste produced, 90 percent, equivalent to about 180,000 t/day, is collected. Of the waste collected in 2011, 58 percent was disposed of in sanitary landfills, 24 percent went to controlled landfills, and 17 percent ended up in dumpsites. This means that some 75,000 t/day are still improperly deposited in dumpsites or controlled landfills, which lack the systems and procedures necessary to protect the environment against damage and degradation. Despite all legal determinations and efforts, improper USW disposal continues to be common practice in all Brazilian states.

According to the data available for 2011, the Southeast Region generates about half of the total waste produced in Brazil, or 97,000 t/day. In second place comes the Northeast Region, which produces about 50,000 tons of waste per day (25%), followed by the South, the Mid-West and the North, each of which generates about 7% to 10%.

The available data also show that the Southeast and South have greater percentages of waste disposed at sanitary landfills (72% and 70%, respectively) compared to the other regions, whereas the North has the highest amount of dumpsite disposal (35%).

Final disposal sites have potential to develop greenhouse gas (GHG) mitigation projects, as the final product of decomposition of solid waste under confined, oxygen-free conditions is biogas, a methane-rich GHG.
Basically, mitigation projects consist in the capture, flaring and/or use of the energy content of biogas to produce electricity and heat, or to be used as natural gas following treatment, thereby preventing its emission to the atmosphere.

Such mitigation projects are eligible to take part in the well-known “international carbon markets”. The main scheme that was being used for these projects was the Clean Development Mechanism (CDM). However, given the uncertainty surrounding the results of international negotiations related to future GHG emission reduction agreements and, consequently, price estimates of the emission reductions to be produced by the projects, as well as the complexity of the CDM procedures, new carbon platforms in the voluntary market are turning out to be interesting for this kind of project. One example is the Verified Carbon Standard (VCS), which is similar to the CDM in many aspects, but has more streamlined procedures and is not subject to regulatory issues and decisions involving international negotiations.

By June 2012, 10,266 projects had been or were being developed under the CDM. By late December, however, only 5,511 projects had been registered under the United Nations Framework Convention on Climate Change (UNFCCC). Most of the registered CDM projects are located in China, with 48.9% of the total. Brazil has 4.7 percent of the registered projects.

With regards to the type and category of the registered projects, most of them fall under the Energy Industries category, which includes mainly renewable energy projects and represents almost 70 percent of the total CDM projects on a global basis.

The solid waste sector accounts for about 13 percent of all registered CDM projects. This sector includes projects involving landfills, waste utilization (composting, incineration, gasification, RDF), manure management, and wastewater.

To date, 46 CDM projects and one Program of Activities (PoA) have been identified in Brazil under “Category 13: waste management and disposal”, sub-category sanitary landfills. These projects are at various stages of the CDM project cycle. Most of the projects – 33 in total – are located in the Southeast Region, followed by the Northeast, South and North Regions, with 7, 4, and 2 projects, respectively. No projects have been identified in the Mid-West Region.

Of the 46 projects mentioned above, 23 projects (50%) consider capture/flaring of recovered biogas. Of these, 15 projects (65%) are in the Southeast Region, followed by the South Region, with 4 projects (18%); the Northeast Region with 3 projects (16%) and the North Region with a single project (4%).

The remaining 50 percent include energy utilization of biogas. Of these, 22 include energy generation and only one considers purifying biogas for injection into a natural gas network. The overall installed capacity stated for electricity generation in the verified Project Design Documents (PDDs) of these projects is 254 MW.

Of all registered CDM Brazilian projects that include an electricity generation component from biogas in their PDD, only two reported electricity generation, namely: Bandeirantes and São João landfill gas projects.
Both are located in the Southeast Region, in the state of São Paulo. Bandeirantes generated 755,700 MWh between 2004 and 2010, while São João generated about 476,900 MWh from March 2008 to May 2012, adding up to a total of about 1.2 million MWh.

The Brazilian National Policy on Solid Waste (known by its acronym in Portuguese, PNRS), which was passed on August 2, 2010, provides the key regulatory framework for the waste sector in the country, and shall hopefully have a positive impact. By seeking better waste treatment quality, promoting the separation and proper disposal of waste, prioritizing recycling for packages, and creating favorable conditions for the introduction of inter-municipal consortia, the PNRS brings sustainability matters to waste-related procedures. This has a direct impact on the development of new opportunities for implementation of biogas capture projects in landfills, with the consequent production of energy and GHG emission reductions.

Furthermore, in late-2009, the Brazilian Government assumed a voluntary, nationwide commitment to set mitigation measures in order to reduce the country’s emissions by 36.1 – 38.9% against their Business-as-usual for 2020. This commitment was established under Law # 12,187 of December 29, 2009, which launched the National Policy on Climate Change (PNMC). The PNMC was regulated by Decree # 7,390 of December 9, 2010.

There is currently no specific legislation in Brazil that specifically refers to a GHG emission reduction plan for solid waste and landfills; however, discussions to implement such a plan are already under way. Authorities are also analyzing the possibility of creating a national cap and trade carbon market, similar to those which are being set up by several countries and states worldwide.

Numerous models have been proposed to predict the amount of methane produced throughout the lifetime of a landfill. These models generally fall into four different categories: zero-order, first-order, multi-phase, and second-order. All these models need basic information in order to estimate the biogas generation potential. More accurate models require more parameters.

Typically, one must know at least the amount of disposed waste, the composition and characteristics of the waste, and the environmental conditions of the zone in which the landfill is located, such as temperature and precipitation. Additionally, knowledge of the operational conditions in the landfill makes it possible to make some adjustments that will allow for more accurate results during modeling.

The IPCC method was chosen for the estimation of biogas in the different waste disposal sites and Brazilian regions. The main reason for choosing this method was availability of information; besides, this method is consistent with the method used to carry out inventories and national GHG emission communications.

A thirty year time span covering between 2009 and 2039 was chosen for the modeling exercise. The results indicate that over this period waste disposal could produce about 892 million CO₂e, which represents an average of 29.7 million tons/yr. The Southeast Region is estimated to generate about 60% of the emissions in Brazil, followed by the Northeast, with 18%. The Mid-West and South regions would generate about 8% each, and finally, the North Region would be responsible for about 6%.

With regards to how GHG emissions would be distributed according to the type of final disposal and region, about 69% of the emissions in sanitary landfills would occur in sites in the Southeast Region, while the Northeast Region would have the highest share in dumpsite emissions.
Based on the results of the modeling and by applying some conservative assumptions for energy-from-landfill-gas, Brazil has an energy potential of about 282 MW additional to that expected from already-registered CDM projects. This is a preliminary figure, which may vary depending on operational conditions in Brazilian sanitary landfills. The highest potential lies clearly in the Southeast Region, which could potentially reach 170 MW in installed capacity. The Northeast Region has a potential of 49 MW, while the South, Mid-West and North have similar capacities of 23 MW, 22 MW and 18 MW, respectively.

Finally, the last part of the document illustrates some case studies related to recovery, flaring and utilization of biogas at three waste disposal sites in Brazil. The main purpose of these case studies is to show how these kind of projects are usually assessed, as well as the results and conclusions obtained in each case.
As a first step in the development of the Brazilian GHG Emission and Energy Atlas, the context of the municipal solid waste (MSW) industry in Brazil, and how MSW is disposed of in the country is examined.

With this in mind, we used the most recent reference data reported by ABRELPE in its study “Panorama dos Resíduos Sólidos Brasil 2011” (Brazil Solid Waste Outlook 2011).

ABRELPE is an organization of companies that works towards creating, expanding, developing and strengthening the solid waste management market, in collaboration with public and private sectors, with the aim of improving operating conditions for the companies. It focuses on proactively disseminating new techniques and promoting and universalizing solid waste management procedures in Brazil, and positioning itself as a reference for environmental sustainability.

The information used in this section includes generation and type of final waste disposal amongst the different Brazilian regions and states during 2010 and 2011.

In 2011, Brazil produced approximately 198,000 tons of MSW/day, equivalent to about 62 million tons/year. About 90% of the total waste produced – i.e., about 180,000 t/day of waste – was collected. Of this, 58% was disposed of in sanitary landfills, 24% went to controlled landfills, and 17% to dumpsites. This means that some 75,000 t/day are still improperly transferred to dumpsites or controlled landfills, which lack the systems and procedures necessary to protect the environment against damage and degradation. Despite all legal determinations and efforts, improper MSW disposal continues to be a normal practice in all Brazilian states.

The following tables and charts summarize the status of generation, collection and disposal per region and state in Brazil in 2010 and 2011:
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<th>Generated MSW (t/day)</th>
<th>Collected MSW (t/day)</th>
<th>Sanitary Landfill (t/day) %</th>
<th>Controlled Landfill (t/day) %</th>
<th>Dumpsite Landfill (t/day) %</th>
</tr>
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<tbody>
<tr>
<td>North</td>
<td>11,360</td>
<td>12,920</td>
<td>13,658</td>
<td>3,694</td>
<td>34.8%</td>
</tr>
<tr>
<td>North-East</td>
<td>38,118</td>
<td>39,092</td>
<td>50,045</td>
<td>50,962</td>
<td>34.2%</td>
</tr>
<tr>
<td>North-West</td>
<td>14,449</td>
<td>15,539</td>
<td>15,824</td>
<td>6,790</td>
<td>48.6%</td>
</tr>
<tr>
<td>Northeast</td>
<td>20,451</td>
<td>20,777</td>
<td>13,045</td>
<td>6,900</td>
<td>35.3%</td>
</tr>
<tr>
<td>South</td>
<td>92,167</td>
<td>93,911</td>
<td>96,134</td>
<td>66,115</td>
<td>71.7%</td>
</tr>
<tr>
<td>South-East</td>
<td>17,920</td>
<td>18,759</td>
<td>21,077</td>
<td>13,045</td>
<td>61.7%</td>
</tr>
<tr>
<td>South-West</td>
<td>13,967</td>
<td>14,449</td>
<td>15,539</td>
<td>6,790</td>
<td>48.6%</td>
</tr>
<tr>
<td>Total</td>
<td>173,633</td>
<td>177,995</td>
<td>200,088</td>
<td>138,924</td>
<td>71.0%</td>
</tr>
</tbody>
</table>

Source: Prepared by MGM Innova with data provided by ABRELPE
As per available data, in 2011, the Southeast Region was responsible for about half of the total waste generated in the country, i.e., 97,000 t/day (49% of total waste). The second largest region in terms of waste generation was the Northeast, which produced 50,000 t/day (22% of total waste). The South, Mid-West and North Regions each contribute 7% to 10% of the total waste.

Again, according to available data, the Southeast and the South have a greater percentage of waste disposed at controlled landfills (72% and 70%, respectively), whereas the North region has the highest disposal rate in dumpsites (35%).

As described in an upcoming section, this distribution of the MSW final disposal has a direct impact on biogas generation.

Figure 1. MSW Collected and Generated in Brazil per Region – 2011
Source: Prepared with data provided by ABRELPE

Figure 2. Distribution of the Amount of MSW Generated and Collected per Region – 2011
Source: Prepared with data provided by ABRELPE
1.1 National Solid Waste Policy (PNRS)

The Brazilian National Policy on Solid Waste (known by its acronym in Portuguese, PNRS), which was passed on August 2, 2010, is considered key for the solution of the waste problem in Brazil, as it contributes to tackle environmental, social and economical issues. The PNRS determines the targets and rules to be followed by the stakeholders involved in different cycles of production of solid waste.

The following are some of the relevant topics covered by the PNRS:

1. Closure of dumpsites and their replacement with sanitary landfills by 2014;
2. Development of solid waste management plans with municipalities, guiding them and their citizens on how to properly manage waste;
3. Development of sector agreements among the generation and consumption chain, aiming to enforce a shared responsibility for the product life cycle.
By seeking better waste treatment quality, promoting the separation and proper disposal of waste, prioritizing recycling for packages, and creating favorable conditions for the introduction of inter-municipal consortia, the PNRS brings sustainability matters to waste-related procedures. This has a direct impact on the development of new opportunities for implementation of biogas capture projects in landfills, with the consequent production of energy and GHG emission reductions.

The forecasts and opportunities created by the PNRS are very promising, even though the path ahead remains long and challenging. One of the main barriers to this process has already been overcome: the approval of the PNRS after years of discussion. Its Enforcement Decree was published on December 23, 2010; what remains now is to work so that the community mobilizes for the PNRS to become a real, effective sustainability asset for the country.
2.1 Climate Change

The IPCC defines climate change as “any change in climate over time, whether due to natural variability or as a result of human activity.” The IPCC concluded that climate change has an impact on and increases the vulnerability of ecosystems, hydro resources, food safety, settlements and communities, and human health.

Climate change is considered a global environmental problem, in contrary of the local air pollution, as the smog caused by the emission of regulated pollutants (SOx, NOx, ozone and particles). Scientists highlight the increasing of the average temperature (United States Global Change Research Program, 2012), meanwhile some analysts observe the increase of extreme climate events.

The Kyoto Protocol (KP) is an international UN-sponsored agreement, signed in 1997 by 59 countries in the city of Kyoto, Japan. The Protocol is within the scope of the United Nations Framework Convention on Climate Change, aimed at reducing the emissions of Greenhouse Gases (GHG) in industrialized nations – through actions that correspond to an average reduction of 5% over the amount emitted by the country in 1990 – and establishing a clean development model for emerging countries. The KP recognizes six Greenhouse Gases (GHG): CO2, CH4, N2O, PFCs, HFCs, and SF6.

Besides acknowledging greenhouse gases, the Protocol also separated the participating countries into two groups:

- **Annex I** – Industrialized countries that committed to reach carbon levels equivalent to 5% below their 1990 emissions during 2008 – 2012.
- **Non-Annex I** – Developing countries, among these, Brazil.
In order to standardize GHG emissions, the Global Warming Potential (GWP) for the emitted gases was established. The GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide.

The GWP allows emissions of methane, nitrous oxide and other high-GWP compounds to be measured in terms of “carbon dioxide equivalent”. The carbon dioxide equivalent, or CO₂ equivalent (CO₂e), is the carbon currency discussed during this report.

### 2.2 The Carbon Markets

In order to meet their targets under the Kyoto Protocol, the European Union countries signed an agreement to reduce their GHG emissions, which resulted in the European Union Emission Trading System (EU ETS). This purpose also resulted in the creation of the flexible mechanisms defined by the Kyoto Protocol, where industrialized countries can import emission reductions from projects in developing countries to meet their own targets. Under the Kyoto Protocol, industrialized countries that could not meet their targets can purchase credits from other nations.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Global Warming Potential (GWP)¹</th>
<th>Typical Sources²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1</td>
<td>Urban solid waste, fossil combustion, land use change, deforestation, cement production</td>
</tr>
<tr>
<td>CH₄</td>
<td>21 (25)</td>
<td>Urban solid waste, agriculture (rice production), waste landfills, animal handling, coal mines</td>
</tr>
<tr>
<td>N₂O</td>
<td>310 (298)</td>
<td>Fertilizer production and application, sewage</td>
</tr>
<tr>
<td>PFCs</td>
<td>CF₆: 6,500 (7,390) C₂F₆: 9,200 (12,200)</td>
<td>Aluminum production</td>
</tr>
<tr>
<td>HFCs</td>
<td>HFC-23: 11,700 (14,800)</td>
<td>Refrigerants</td>
</tr>
<tr>
<td>SF₆</td>
<td>23,900 (22,800)</td>
<td>Power transformers, magnesium production</td>
</tr>
</tbody>
</table>

¹ The first number shown refers to the values recognized by the Kyoto Protocol, and is based on the IPCC Second Assessment Report (SAR, 1995). Values in brackets are the most recent values based on the IPCC Fourth Assessment Report (AR4, 2007).
2.3 Market Types: Emission Allowances
X Offsets

The two main assets traded in the EU ETS carbon market are the European Union Allowances (EUA), and the carbon “offsets” generated by GHG emission reduction projects.

Under a compulsory regime that sets a cap for emissions and creates an international/regional trading allowance system (“cap-and-trade”), emission allowances are distributed to the emission sources authorizing them to emit a certain amount of tCO₂e over a given period of time. If an emission source exceeds the emission cap defined by the allowances, said source can purchase excess emission allowances from other market players, and/or purchase offset credits (each credit equals 1 tCO₂e reduced) generated from emission reduction projects. A number of “cap-and-trade” programs use emission allowances and offsets to meet their targets under the Kyoto Protocol or national regulations.

2.3.1 Emission Allowances

Emission allowances are created by governments and distributed to the market players. This early operation forms the primary market for emission allowances. Governments can distribute licenses by several ways, for instance, by selling licenses either through a bidding process or at a fixed price. Governments can also provide emission allowances through free distribution, also referred to as “allocation”, or can have a “hybrid” approach by using allocations and offering fixed or variable prices under an auction to distribute the emission allowances.

2.3.2 Offsets

The Greenhouse Gas Offsets generated by emission reduction projects are often sold before the credits are actually issued, through market operations in which the project owner sells the carbon credits generated by the project to a purchaser. These offsets are typically sold at a relatively low price, given the risks assumed by the buyer in terms of the uncertainties surrounding the volume he shall finally receive, and the price of the credits at the time of issuance. Once these offsets are actually issued, they can be traded as a commodity in the secondary markets.

Regarding transaction structure, emission allowances and carbon offsets are sold on future and spot markets. Secondary trading takes place under two main channels: multilateral exchanges, and direct negotiation between the parties, with or without third-party mediation. This is known as “over-the-counter” trading (OTC).

Market players include regulated entities with a natural demand for emission allowances and offsets as instruments to comply with targets, brokers, market creators or resellers, and other private-capital participants who can trade on their own for a profit.
2.4 Voluntary X Regulated Markets

“There are two types of carbon markets. The first market is created under commitment requests, that is, a regulated market, where transactions are done under some kind of normative restriction within an international, regional, national or local scope. The second one is the voluntary market, where the transaction responds to a free decision of the purchaser. In some cases, voluntary markets arise with an expectation of anticipating regulated markets that take time to be negotiated or have tight restrictions that limit access to them, or with the investors’ expectation of purchasing cheap credits with the forecast of higher future prices, or even to meet the reputation policies of some companies” (SMERALDI, 2009).

2.4.1 Regulated Market

The European Union Emissions Trading System (EU ETS) is the world’s largest regulated carbon market, as shown in Table 3 and highlighted in orange in Figure 4. The EU ETS includes 27 countries and allows the import of emission reductions generated in projects in Non-Annex I countries to meet national emission reduction targets set for the European Union member states.

The Kyoto Protocol comprises three regulated flexibility mechanisms: Clean Development Mechanism (CDM), Joint Implementation (JI) and Emission Trading. Of these, the Clean Development Mechanism (CDM) is the biggest source of GHG emission offsetting projects, as shown in Table 3. Countries highlighted in green have

Figure 4. Regulated and Voluntary Emission Markets per Region
Source: UNFCCC, WCI, RGGI websites; created by Molly Peters-Stanley for Ecosystem Market Place and Bloomberg. New Energy Finance, 2010
registered CDM projects, which issue certificates for a person or company that reduced their emissions, known as Certified Emission Reductions (CERs). Countries highlighted in purple are eligible for CDM projects, but have no CDM projects at all. Finally, countries in dark grey are eligible to host JI projects and produce Emission Reduction Units (ERUs).

The United States of America did not ratify the Kyoto Protocol, but is a host for several regional markets such as the Regional Greenhouse Gas Initiative (RGGI) and the Western Climate Initiative (WCI), and California’s cap-and-trade system, which begins to operate in 2013 for the largest industrial and power generation units. Various Canadian provinces should also participate in the WCI.

The Table 3 shows the importance of the EU ETS market for global emission trading. As the world’s largest regulated carbon trading scheme, the EU trade is based on public and industrial services, investment banks, and power trading companies. Although most of the trade under the EU regulated market are focused on operations with Emission Unit Allowances (EUA), there is also a significant market for CER trading. Japan has also been a key CER purchaser and is an important source of demand in the primary markets. It should be noted that Japan currently does not have an internal carbon trading regime, although it does have emission reduction commitments under the Kyoto Protocol.

### 2.4.2 Voluntary Market

In addition to the markets mentioned above, new voluntary markets continue to arise. The voluntary market has been growing steadily, and is now starting to cross national boundaries and consolidate worldwide.

The voluntary market was created about 20 years ago, when the first emission offset forest conservation projects began to appear. These projects had always raised criticism regarding their effectiveness and the permanence of the ensuing emission reductions, so that the more “innovative” projects that did not find their place in the compulsory market tended to end up as voluntary schemes.

<table>
<thead>
<tr>
<th>Table 3. Traded Volumes, Global Carbon Market – 2009 and 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source: FOREST TRENDS, 2011</td>
</tr>
<tr>
<td><strong>Carbon Market</strong></td>
</tr>
<tr>
<td>EU ETS</td>
</tr>
<tr>
<td>Primary CDM</td>
</tr>
<tr>
<td>Total Voluntary Market</td>
</tr>
</tbody>
</table>
Over the years, standards have developed together with private registries to offer credits with more credible warranties, and the voluntary market have become more “acceptable” to critics. Even compulsory schemes such as California’s cap-and-trade now recognize voluntary market standards.

The main platforms of the carbon voluntary market include the “Verified Carbon Standard” (VCS – formerly known as “Voluntary Carbon Standard”, the “Gold Standard” (GS), and the “American Carbon Registry” (ACR). Figure 5 shows the main platforms of the voluntary carbon market, and their market share.

Another example of voluntary initiatives can be found in China, where five provinces and eight cities have been identified as candidates to the early insertion in the voluntary carbon market.

2.5 Bilateral Agreements: The Japanese Case

Japan has proposed a new carbon offsetting scheme that aims to streamline the UN-established process for approval of CDM projects, and to make it easier for developing countries access to Japan’s clean energy technology.

The idea of proposing a new offsetting scheme derived from the difficulties project sponsors in developing countries faced in registering their GHG emission reduction projects under the CDM, largely due to the complexity and slowness of this system; and because of the difficulties faced by Japanese companies to obtain the reductions purchased to meet their reduction targets.

According to a study carried out by Japan’s Institute for Global Environmental Strategies (IGES), there are currently significant opportunities not only to improve on the CDM, but also to promote additional emission reductions and help developing countries achieve sustainable development.
As per the aforementioned study, today’s greatest barrier is the uncertainty regarding whether a project will be registered as a CDM project, and whether the CERs will be issued as expected, and this is hindering potential investments in projects that would not occur without the CDM. Such uncertainty derives from the “judgment” of several different entities. In particular, project additionality and emission reductions calculations are the two most controversial subjects that have to be judged on a case-by-case basis by different entities.

The mechanisms proposed by Japan to be developed under bilateral agreements will differ significantly from those existing under the Kyoto Protocol and will be implemented outside the UN’s plans, thereby speeding up the entire process. The key elements of Japan’s new offsetting scheme are:

1. Quick, effective decisions under the bilateral procedure;
2. Inclusion of a broader range of technologies for mitigation of the negative effects caused by climate change;
3. Setting up the first essential steps towards a global regime (METI, 2010);
4. Feasible rules for determination of additionality;
5. Proper use of statistical methods for the monitoring and verification of emission reductions.

Through this new mechanism, the Japanese government expects to meet part of its emission reduction targets through credits generated by projects developed between Japan and a partner country. Under such an agreement, the project might sell the credits to Japan or use part of them to meet their own emission reduction targets, such as commitments under the “Copenhagen Accord”.

The structure of the bilateral program is currently under construction, but some key steps have already been taken for the development of carbon credit projects. The first step Japan’s government is currently working on is the search for opportunities in developing countries. A number of feasibility studies have been carried out in Asia and Latin America in order to implement emission reduction projects under bilateral agreements.

Some steps of the validation for registration, quantification, reporting, checking and final certification of carbon credits are similar to those in place for CDM projects, but are more efficient, since they include simplified methodologies, retroactive approval of activities, and quicker procedures. Figure 6 shows the basic structure of the new offset mechanism under the bilateral agreements.

Figure 6. Basic Structure of the New Offset Mechanism under the Bilateral Agreements
2.6 The post-2012 Context

On a yearly basis, the member states of the United Nations Framework Convention on Climate Change (UNFCCC) gather for a summit known as Conference of the Parties (COP). The 17th edition of the COP was held in Durban in 2011, where 194 states discussed the scenario of climate change and the decisions for the post-2012 (end of the Kyoto Protocol’s first commitment period).

Several important decisions on GHG emission reductions were taken, which pushed down the CER prices. Among them:

- Approval of an EU-proposed roadmap for the development of a global emission reductions treaty (legal framework) against climate change by 2015;
- Approval of the second Kyoto commitment period, from January 1st 2013 to December 2017 or December 2020. The final date would be decided by the parties during 2012;
- The global agreement would involve all nations (including the main GHG emitters) and would enter into force in 2020; its rules would in all likelihood differ from those of Kyoto’s first period;
- Russia, Japan and Canada have already anticipated that they will not participate in the second commitment period of Kyoto.

With these three big economic powers countries stepping out to migrate to other carbon markets, reliability on the regulated market decreases. Furthermore, there shall be a number of changes in regulations during the second Kyoto period, which added to the global economic recession and the lower demand for carbon credits, will in all probability result in a fall in the price of CERs.

Within the carbon markets scenario, it should be noted that over the last 18 months in some cases VERs\(^1\) have traded at twice the price of CERs\(^2\). During this period, almost 90% of the CERs were traded at an average price of €1.50, whereas Gold Standard VERs traded at €3.50 – 15.00 (Gold Standard certification, the voluntary market for top quality voluntary projects). In contrast to CERs, which trade as commodities, the price of voluntary credits is highly contingent on the type of project from which they derive.\(^3\)

According to a Reuters article:

“U.N. carbon permits, called certified emissions reductions (CERs), have lost more than 70 percent of their value over the past year on the continued over-supply of permits, low demand due to the global economic downturn and concerns about restrictions on CER use in other countries’ carbon” (CARBONO BRASIL, 2012).

This may be an indication that carbon supply is being driven to the voluntary market, which was once considered unreliable and less rigorous in terms of quality. However, the voluntary market has proven to be more interesting for companies that not only want to trade their carbon credits but are also seeking to publicize their environmental credentials. One example of this is the growing number of buyers from the Middle East in the voluntary market, as these countries with a high oil and gas production activity have become more interested in reporting their emissions.

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\(^1\) GHG emission unit verified by an independent auditor, and normally designed to emissions reductions for the voluntary market.

\(^2\) GHG emission unit issued under the Kyoto Protocol’s Clean Development Mechanism (CDM).

\(^3\) Information available in: http://www.pointcarbon.com/news/1.2004453
Another factor underlying the growth of the voluntary market is the new restrictions imposed by the EU ETS. As of 2013, CERs from projects registered after December 31, 2012 and located outside the scope of the least developed countries can no longer be traded on the EU ETS. Many of these credits might make their way to the voluntary market. This trend has a negative effect on the progress of the CDM within the BRICs (the group of developing countries that includes Brazil, Russia, India, China and South Africa), since investments from the European Market will be eliminated.

More attractive prices and simpler procedures to achieve project registration are also factors that push companies seeking to cut their expenses to move to the voluntary market. According to the International Emissions Trading Association (IETA) report on the GHG Market in 2012, there has been an increase in independent emission programs, a number of national systems have arisen, and governments are seeking more tools to develop their legislations and set out carbon credit systems, especially in North America, Asia and Australia.

In addition, the increase of regulated emission programs in California, Québec, Australia, China and South Korea continues to be a political choice for worldwide emission reductions.

### 2.7 Considerations on the Brazilian Legislation

In late-2009, the Brazilian Government assumed a voluntary, nationwide commitment to set mitigation measures in order to reduce the country’s emissions by 36.1 – 38.9% against their business-as-usual for 2020. This commitment was established under Law # 12,187 of December 29, 2009, which launched the National Policy on Climate Change (PNMC). The PNMC was regulated by Decree # 7,390 of December 9, 2010.

Much of the Brazilian emissions reductions derive from reduced deforestation, especially in the Amazon region. Under this context, two Action Plans are underway: the first plan aims at limiting deforestation in the Amazon rainforest, whilst the second aims at tackling deforestation in the Brazilian Cerrado, Brazil’s second most threatened biome. For the Amazon, Brazil’s aim is to reduce deforestation by 80% by 2020. For the Cerrado, the reduction target is of 40%.

The targets are:

- Reduced deforestation in the Amazon rainforest (estimated reduction: 564 million tCO₂ by 2020);
- Reduced deforestation in the Cerrado (estimated reduction: 10.4 million tCO₂ by 2020);
- Restoration of pasture areas (estimated reduction: 83 – 104 million tCO₂ by 2020);
- Integrated harvest-cattle system (estimated reduction: 18 – 22 million tCO₂ by 2020);
- Direct planting (estimated reduction: 16 – 20 million tCO₂ by 2020);
- Biological nitrogen fixation (estimated reduction: 16 – 20 million tCO₂ by 2020);
- Energy efficiency (estimated reduction: 12 – 15 million tCO₂ by 2020);
- Increased use of biodiesel (estimated reduction: 48 – 60 million tCO₂ by 2020);

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1. The first large-scale carbon market, created in 2005
2. The list of the least developed countries can be found in: [http://unfccc.int/resource/docs/publications/ldc_brochure2009.pdf](http://unfccc.int/resource/docs/publications/ldc_brochure2009.pdf)
• Increased hydropower supply (estimated reduction: 79 – 99 million tCO₂ by 2020);
• Alternative energy sources (estimated reduction: 26 – 33 million tCO₂ by 2020);
• Steel industry (switching of deforestation-based coal for plantation-based coal. Estimated reduction: 8 – 10 million tCO₂ by 2020).

Four sector plans are already being carried out: the Plan for Prevention and Control of Deforestation in the Amazon (PPCDAm), the Plan for Prevention and Control of Deforestation in the Cerrado (PPCerrado), and the Sector Plans for Energy and Agriculture. Another six sector plans are under the final stage for approval, and include: Steel, Transport, Mining, Manufacturing, Health, and Fishery and Aquaculture.

There is no specific legislation in Brazil that specifically refers to a GHG emission reduction plan for solid waste and landfills. However, the potential inclusion of such legislation in this sector has been discussed, and new segments might be adopted for the years to come, such as hydro resources and solid waste, among others.

Another important aspect to consider is the possibility of the creation of a Brazilian carbon market, which could allow credit trading among the regulated sectors and set reduction targets. This trading scheme is being studied by Brazilian authorities, and could reflect realities that are consolidated in other countries.
CDM projects: capture, flaring, and use of biogas in Brazilian sanitary landfills

In this section, we will analyze projects aimed at biogas capture, flaring and utilization that applied the CDM in Brazil.

Data in this section were directly obtained from publicly available information on the UNFCCC\(^7\) website and other sites that perform statistical analyses of CDM projects, such as IGES\(^8\) and the UNEP Risoe Centre’s CD4CDM\(^9\).

Prior to showing the analysis of CDM projects in Brazilian sanitary landfills, we will present a brief contextualization of the status of CDM projects on a worldwide basis.

To date\(^{10}\), 10,266 projects have been developed under the CDM. Currently, these projects are in the following stages:

- 4,170 were registered;
- 135 are under registration;
- 4,279 are under validation;
- 57 were withdrawn by project proponents;
- 222 were rejected by the CDM Executive Board;
- 206 received a negative validation report;
- 1,197 had their validation cancelled.

China is the country with the highest amount of registered CDM projects, with 48.9% of the total. Brazil has 4.74% of the registered projects. Figure 7 shows the percentage participation of the main countries with CDM projects, including: India, Brazil, Mexico, Vietnam, Malaysia, and Indonesia, among others.

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\(^7\) http://cdm.unfccc.int/Projects/projsearch.html

\(^8\) http://www.iges.or.jp/en/pub/index.html

\(^9\) http://cd4cdm.org/

\(^{10}\) June 3rd, 2012
Regarding type and category of the registered projects, most fall under the Energy Industries category, which mainly includes renewable source projects. This category represents almost 70% of all CDM projects on a global basis.

Solid waste handling and disposal accounts for 13.02% of all registered CDM projects (650 projects). This includes landfill projects, waste utilization (composting, incineration, gasification, RDF), manure handling, and wastewaters.

Figure 7. Registered Projects by Host Country

Figure 8. Distribution of Registered CDM Projects by Category
Figure 8 shows the distribution of registered CDM projects by category.

According to the review and investigation carried out for Brazil, to date 46 CDM projects and one Program of Activities (PoA) were identified within “Category 13: waste management and disposal”, sub-category sanitary landfills. These projects are at different stages of the CDM project cycle:

- 28 projects were registered;
- 15 projects are under validation;
- 1 project has been withdrawn;
- 2 projects had their validation cancelled.

Figure 9 shows the number of CDM projects in landfills per region. It is clear that the Southeast Region has the most projects of the kind, 33 in total; the Northeast, South and North have 7, 4, and 2 projects, respectively. No projects are reported in the Mid-West Region.

Figure 10 shows the percentage of CDM projects per region.

Landfill CDM projects in Brazil could potentially lead to emission reductions of 12.1 mtCO₂e per year, with the Southeast Region accounting for 8,603 ktCO₂e (71%). Figure 11 provides an estimation of the potential GHG emission reductions from CDM projects being developed in each region.

As mentioned previously, there are currently 28 CDM projects for sanitary landfills in Brazil that are registered with the UNFCCC and are entitled to produce Certified Emission Reductions (CER). Figure 12 shows the number of registered CDM projects per region. The Southeast has 18 registered projects (64%), while Northeast, South and North have 5, 3 and 2 projects, respectively. Figure 13 shows the percentage distribution of registered CDM projects per region.

**Figure 9. CDM Projects per region**

Source: Prepared by MGM with official data from the UNFCCC
Figure 10. Distribution of CDM projects per region
Source: Prepared by MGM with official data from the UNFCCC

Figure 11. GHG emission reduction potential per year from CDM projects per region
Source: Prepared by MGM with official data from the UNFCCC

Figure 12. Registered CDM projects per region
Source: Prepared by MGM with official data from the UNFCCC
**Figure 13.** Distribution of registered CDM projects per region
Source: Prepared by MGM with official data from the UNFCCC

**Figure 14.** Generated CERs per region
Source: Prepared by MGM with official data from the UNFCCC

**Figure 15.** Installed capacity stated in PDDs for biogas-powered generation
Source: Prepared by MGM with official data from the UNFCCC
Of the 28 registered CDM projects, 19 effectively produced carbon credits (CERs, represented in tons of carbon dioxide equivalent – tCO₂e), which amounted to about 9.1 million tCO₂e to date. 90% of the CERs were produced in the Southeast Region (8.2 million tCO₂e), followed by the North, with 0.48 million (5%), the South, with 0.35 million tCO₂e (4%), and the Northeast, with 0.05 million tCO₂e (1%). The Mid-West Region did not produce CERs. Figure 14 shows the amount of CERs produced per region to date.

Of the 46 projects developed under the CDM, 21 include power generation from biogas. According to their Project Design Documents (PDDs), these 21 projects have a considered installed capacity of 254 MW. Figure 15 provides the reported capacity per region.

### 3.1 Approved and under approval CDM methodologies for sanitary landfills

A methodology previously approved by the Meth Panel (MP) and the CDM Executive Board (CDM EB) must be used in order to design and develop a CDM project.

These methodologies describe different aspects that must be considered in order to demonstrate that the project qualifies under the CDM, such as methodology applicability and additionality criteria. The methodologies also describe the calculation procedures that must be applied in order to estimate the GHG emission reductions from the project, and the monitoring features required to ensure that project proponents correctly quantify project emission reductions.

Under CDM rules, there are two large categories of methodologies, based on project size: 1) large-scale methodologies, and 2) small-scale methodologies.

For the specific case of sanitary landfill projects, the difference between methodology categories is defined by the amount of GHG emission reductions that can be achieved from a particular activity. A project that is expected to produce less than 60,000 tCO₂e/yr can use small-scale methodologies, while large-scale methodologies must be used in those projects estimated to generate more than 60,000 tCO₂e/yr in emission reductions.

Under the procedures established by the CDM Executive Board, methodologies use the nomenclature below, followed by a consecutive number:

- AM#### = Approved Methodology
- ACM#### = Approved Consolidated Methodology
- AMS-III.## = Approved Small-scale Methodology

The following is a brief description of the methodologies in place for mitigation in landfills under the CDM.

#### 3.1.1 Large scale

**ACM0001: Flaring or use of landfill gas – Versão 13.0.0**

Sanitary landfill methodologies were popular at the beginning of the CDM; different project proponents led to the development of different methodologies, each one with their specific conditions, but a common aim: to reduce GHG emissions in landfills.
Likewise, before the consolidated methodology ACM0001 came into place, other large-scale methodologies that are no longer in use were applied for some projects in Brazil, such as:

- AM0002: Greenhouse gas emission reductions through landfill gas capture and flaring where the baseline is established by a public concession contract (approved based on proposal NM0004-rev: Salvador da Bahia landfill gas project).
- AM0010: Landfill gas capture and electricity generation projects where landfill gas capture is not mandated by law (approved based on proposal NM0010-rev: Durban-landfill-gas-to-electricity project).
- AM0011: Landfill gas recovery with electricity generation and no capture or destruction of methane in the baseline scenario (approved based on proposal NM0021: Cerupt methodology for landfill gas recovery).

Methodology ACM0001 is the most applied for CDM landfill projects in Brazil and worldwide. In Brazil, 36 projects (78%) follow this methodology in this sector.

Basically, this methodology states that biogas recovered by the proposed project activity may be incinerated or used to generate electricity, for thermal use, or be purified and injected in a natural gas network.

Calculation of emission reductions must be carried out ex-ante. In order to reflect this, the methodology refers to the following tool: “Emissions from solid waste disposal sites”11. This tool describes how to calculate emissions in final disposal sites. The conditions and criteria required by the tool will be shown in more detail further ahead in this report.

According to the methodology, one must also consider the associated project emissions from electricity and fossil fuel consumption during the implementation of the proposed project activity. Also, in the case of biogas flaring, it is necessary to consider those emissions related to biogas destruction efficiency in the flare. For this purpose, there are tools that describe the calculation procedures and monitoring requests so that these emissions are accurately calculated. These tools are:

- Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion;
- Tool to calculate baseline, project and/or leakage emissions from electricity consumption;
- Tool to determine project emissions from flaring gases containing methane;
- Tool to determine the mass flow of a greenhouse gas in a gaseous stream;
- Emissions from solid waste disposal sites.

Methodology ACM0001 and their associated tools are available at the following UNFCCC website: http://cdm.unfccc.int/methodologies/DB/EYUD9R1ZAUZ2XNZD3HQC18OK3WIV

11 http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-04-v6.0.1.pdf/history_view
Figure 16 summarizes the basic aspects of methodology ACM0001.

**AM00069: Biogenic methane used as feedstock and fuel for town gas production – Version 2.0**

This large-scale methodology allows claiming emission reductions from destruction of CH₄ in biogas, or from total or partial switching of fossil fuels, e.g.: natural gas to purified biogas-based methane.

**Figure 16. Basics of Methodology ACM0001**

Source: CDM Methodology Booklet

<table>
<thead>
<tr>
<th>Typical project(s)</th>
<th>Capture of landfill gas (LFG) and its flaring and/or use to produce energy and/or use to supply consumers through natural gas distribution network.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of GHG emissions mitigation action</td>
<td>GHG destruction.</td>
</tr>
<tr>
<td></td>
<td>Destruction of methane emissions and displacement of a more-GHG-intensive service.</td>
</tr>
<tr>
<td>Important conditions under which the methodology is applicable</td>
<td>• Captured landfill gas is flared, and/or;</td>
</tr>
<tr>
<td></td>
<td>• Captured landfill gas is used to produce energy, and or;</td>
</tr>
<tr>
<td></td>
<td>• Captured gas is used to supply consumers through natural gas distribution network.</td>
</tr>
<tr>
<td>Important parameters</td>
<td>Monitored:</td>
</tr>
<tr>
<td></td>
<td>• Amount of landfill gas captured;</td>
</tr>
<tr>
<td></td>
<td>• Methane fraction in the landfill gas;</td>
</tr>
<tr>
<td></td>
<td>• Flare efficiency (optional);</td>
</tr>
<tr>
<td></td>
<td>• If applicable: electricity generation using landfill gas.</td>
</tr>
</tbody>
</table>

**BASELINE SCENARIO**

LFG from the landfill site is released to the atmosphere

**PROJECT SCENARIO**

LFG from the landfill site is captured and flared; and/or used to produce energy (e.g. electricity/thermal energy); and/or used to supply consumers through natural gas distribution network.
The biogas may come from landfills or wastewater treatment facilities.

This methodology is not widely used. In fact, only two projects have applied this methodology in the world. One of these is the Gramacho Landfill project in Rio de Janeiro, and the other is in Santiago, Chile. The Gramacho project was withdrawn, whereas the Chilean project was registered in February 2011.

The methodology includes some applicability conditions that must be fulfilled for its use.

Methodology AM0069 and their associated tools are available at the following UNFCCC website:
http://cdm.unfccc.int/methodologies/DB/4ZGGL8ZWUVFS1EFF9N6OCAHUXUJQ7T

Figure 17 summarizes the basics of methodology AM0069.

AM00083: Avoidance of landfill gas emissions by in-situ aeration of landfills. Version 1.0.1

This is a relatively new, little used methodology. Unlike ACM0001, where generated biogas is captured and destroyed or used, this methodology aims at the avoidance of biogas generation. This is done by applying different aeration techniques into the waste mass in the landfill, which prevents the occurrence of anaerobic conditions and, eventually, methane production.

As in methodology ACM0001, the mitigation potential must be measured ex-ante with the tool: “Emissions from solid waste disposal sites”.

Methodology AM0083 and its associated tools are available at the following UNFCCC website:
http://cdm.unfccc.int/methodologies/DB/06975K2Y49702WJR8T4SUlQ5173DV

Figure 18 summarizes the basics of methodology AM0083.

AM0093: Avoidance of landfill gas emissions by passive aeration of landfills. Version 1.0.1

This methodology is similar to AM0083, in which the aim is to avoid biogas generation by inducing aeration and then avoid anaerobic decaying processes. The main difference is that methodology AM0093 employs passive aeration to originate semi-aerobic conditions. In order to achieve this, the methodology includes criteria to be fulfilled regarding the setup of the aeration system, thereby ensuring that anaerobic processes will be avoided by means of a passive ventilation system.

Currently, there is no CDM project in the world registered with this methodology.

Methodology AM0093 and their associated tools are available at the following UNFCCC website:
http://cdm.unfccc.int/methodologies/DB/2GD08SZKUBS916SP75HRQT3DZ90H5D

Figure 19 summarizes the basics of methodology AM0093.
**Figure 17. Basics of Methodology AM0069**

*Source: CDM Methodology Booklet*

<table>
<thead>
<tr>
<th>Typical project(s)</th>
<th>Capture of biogas at a wastewater treatment facility or a landfill and use of the biogas to fully or partially substitute natural gas or other fossil fuels as feedstock and fuel for the production of town gas.</th>
</tr>
</thead>
</table>
| Type of GHG emissions mitigation action | • GHG destruction;  
• Renewable energy;  
• Feedstock switch;  
• CH\textsubscript{4} emissions are avoided and fossil fuel is replaced. |
| Important conditions under which the methodology is applicable | • There is no change in the quality of the produced town gas;  
• Town gas consumer and/or distribution grid are within the host country boundaries;  
• Biogas is captured at an existing landfill site or wastewater treatment facility that has at least a three-year record of venting or flaring of biogas. Biogas would continue to be vented or flared in the absence of the project;  
• Project is implemented in an existing town gas factory that used only fossil fuels, no biogas, for at least three years prior to the start of the project. |
| Important parameters Monitored: | • Quantity and caloric value of town gas produced.  
• Quantity and caloric value of the biogas and fossil fuel used as feedstock. |

**BASELINE SCENARIO**
Venting or flaring of biogas at the site where it is captured and use of fossil fuel as feedstock for town gas production.

**PROJECT SCENARIO**
Capture of biogas from landfills and/or waste treatment plants and use of the biogas to replace fossil fuel.
3.1.2 Small scale

**AMS-III.G: Landfill methane recovery – Version 7.0**

This small-scale methodology has a similar structure to large-scale methodology ACM0001. It is focused on project activities to capture biogas from landfills. This methodology allows any of the following actions:

- Biogas flaring;
- Utilization: electricity generation, thermal use and purification for further utilization of biogas;
- Hydrogen production;
- Use as transportation fuel.

Depending on the type of action, other small-scale methodologies can be applied to develop the associated emission reduction component.

AMS-III.G is the second most used methodology for landfill projects, after large-scale methodology ACM0001. There are 28 registered projects that use this methodology in various countries worldwide.
Methodology AMS-III.G and its associated tools are available at the following UNFCCC website:
http://cdm.unfccc.int/methodologies/DB/XMQi6LMZWBPSII7ZFU71T9EFV30BM

Figure 20 summarizes the basics of methodology AMS-III.G.

AMS-III.AX: Methane oxidation layer (MOL) for solid waste disposal sites – Version 1.0.

This methodology applies to project activities involving the construction of a methane oxidation layer (MOL) on top of a municipal solid waste disposal site (SWDS) with low residual surface methane emission. The purpose is to avoid the release of methane through biological oxidation in the MOL.
This methodology was developed for cases in which capture and treatment of biogas is not attractive due to its low concentration.

This methodology is applicable only to enclosed sites that no longer receive waste. No registered project is applying this methodology today.

Methodology AMS-III.AX and its associated tools are available at the following UNFCCC website: http://cdm.unfccc.int/methodologies/DB/A126YTVRWJZ1NR6CFYOA2GY0XUST5Y

Figure 21 summarizes the basics of methodology AMS-III.AX.

<table>
<thead>
<tr>
<th>Typical project(s)</th>
<th>Capture and combustion of methane from landfills used for disposal of residues from human activities including municipal, industrial and other solid wastes containing biodegradable organic matter.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of GHG emissions mitigation action</td>
<td>GHG destruction; Destruction of methane and more-GHG-intensive service displacement.</td>
</tr>
<tr>
<td>Important conditions under which the methodology is applicable</td>
<td>Baseline emissions shall exclude methane emissions that would have to be removed to comply with national or local safety requirement or legal regulations.</td>
</tr>
</tbody>
</table>
| Important parameters | Monitored:  
  - The amount of methane recovered and gainfully used, fuelled or flared shall be monitored ex-post, using continuous flow meters;  
  - Fraction of methane in the landfill gas;  
  - Flare efficiency. |

**BASELINE SCENARIO**

Biomass and other organic matter in waste are left to decay and methane is emitted into the atmosphere.

**PROJECT SCENARIO**

Methane in the landfill gas is captured and destroyed or used. In case of energetic use of landfill gas, displacement of more-GHG-intensive energy generation.

Figure 20. Basics of Methodology AMS-III.G

Source: CDM Methodology Booklet
**Figure 21.** Basics of Methodology AMS-III.AX

Source: CDM Methodology Booklet

<table>
<thead>
<tr>
<th>Typical project(s)</th>
<th>Project activities involving the construction of a methane oxidation layer (MOL) on top of a municipal solid waste disposal site (SWDS) to avoid the release of methane through biological oxidation in the MOL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of GHG emissions mitigation action</td>
<td>GHG destruction. Avoidance of methane emissions from solid waste disposal sites.</td>
</tr>
</tbody>
</table>
| Important conditions under which the methodology is applicable | • It is applicable where landfill gas collection and treatment is not applicable due to low concentration of landfill gas (less than 4 L CH₄·m⁻²·h⁻¹) or other reasons;  
• It is not applicable at SWDS with an active gas extraction system, or that are still receiving wastes for disposal or where a MOL is required by legal regulation. |
| Important parameters | Monitored:  
• Parameters related to methane oxidizing material quality such as TOC, ammonium and nitrite have to be analyzed;  
• Parameters related to MOL construction properties, e.g. thickness of MOL and gas distribution layer/ balancing layer during application;  
• Parameters related to methane oxidation performance, e.g. measured volume fraction of methane in the middle of the distribution layer. |

**BASELINE SCENARIO**

Biomass and other organic matter in waste are left to decay and methane is emitted into the atmosphere.

**PROJECT SCENARIO**

Methane that would have been released is oxidized in the MOL.
3.2 Biogas-flaring CDM Projects developed in Brazil

This section provides an analysis of CDM projects in Brazil involving capture and flaring of biogas.

A total of 23 projects involving capture/flaring of recovered biogas are reported in Brazil, which is about 50% of the CDM projects in the country. Most of the projects (65%) are in the Southeast Region (15 projects). In second place is the South Region, with 4 projects (18%); followed by the Northeast Region with 3 projects (16%) and the North Region, with only one project (4%). There are no registered projects in the Mid-West Region.

Figure 22 and Figure 23 show the quantity and distribution of CDM projects exclusively dedicated to biogas flaring, per region.

Table 4 provides a list of projects per region and state. The table also includes specific project names, project status within the CDM cycle, and applied methodology.
### Table 4. List of biogas-flaring CDM projects developed in Brazil

<table>
<thead>
<tr>
<th>Region</th>
<th>State</th>
<th>Ref# (UNFCCC)</th>
<th>Title</th>
<th>Status</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Pará</td>
<td>888</td>
<td>Aurá Landfill Gas Project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td>Northeast</td>
<td>Bahia</td>
<td>52</td>
<td>Salvador da Bahia Landfill Gas Management Project</td>
<td>Registered</td>
<td>AM2</td>
</tr>
<tr>
<td></td>
<td>Bahia</td>
<td>893</td>
<td>Canabrava Landfill Gas Project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>Espírito Santo</td>
<td>1491</td>
<td>CTRVV Landfill emission reduction project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>Rio de Janeiro</td>
<td>4657</td>
<td>Itaoca Landfill Gas Project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>27</td>
<td>Onyx Landfill Gas Recovery Project – Trêmembé, Brazil</td>
<td>Registered</td>
<td>AM11</td>
</tr>
<tr>
<td></td>
<td>São Paulo</td>
<td>165</td>
<td>ESTRE’s Paulínia Landfill Gas Project (EPLGP)</td>
<td>Registered</td>
<td>AM3</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>171</td>
<td>Caieiras landfill gas emission reduction</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>226</td>
<td></td>
<td>Anaconda Landfill Gas Project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>912</td>
<td></td>
<td>Quitaúna Landfill Gas Project (QLGP)</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>1133</td>
<td></td>
<td>Terrestre Ambiental Landfill Gás Project</td>
<td>Registered</td>
<td>ACM1+ACM2</td>
</tr>
<tr>
<td></td>
<td>1134</td>
<td></td>
<td>ESTRE Pedreira Landfill Gas Project (EPLGP)</td>
<td>Registered</td>
<td>ACM1+ACM2</td>
</tr>
<tr>
<td></td>
<td>1179</td>
<td></td>
<td>Embralixo/Araúna – Bragança Landfill Gas Project</td>
<td>Registered</td>
<td>ACM1+ACM2</td>
</tr>
<tr>
<td></td>
<td>1247</td>
<td></td>
<td>URBAM/ARAUNA – Landfill Gas Project (UALGP)</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>1636</td>
<td></td>
<td>Alto-Tietê landfill gas capture project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>1908</td>
<td>ENGEPE &amp; BEGREEN CDM Project at UTGR – Jambeiro Landfill</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>648</td>
<td></td>
<td>Central de Resíduos do Recreio Landfill Gas Project (CRRLLGP)</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>1506</td>
<td>Proactiva Tijuquinhas Landfill Gas Capture and Flaring project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>Santa Catarina</td>
<td>1908</td>
<td>SANTECH – Saneamento &amp; Tecnologia Ambiental Ltda. – SANTEC Resíduos landfill gas emission reduction Project Activity</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
</tbody>
</table>
3.2.1 CDM projects in Brazil with energy utilization and/or power generation

Of the 46 CDM solid waste/landfill projects in Brazil, 23 (50%) include energy utilization of biogas. Of these, 22 projects include electricity generation and only one project considered purifying biogas for further use within a natural gas network. However, this project was withdrawn by its proponents.

The total installed stated capacity for electricity generation as per the PDDs of these projects is 254 MW. Three Brazilian regions have reported projects of this kind: most of them are in the Southeast, with 16 projects (76%). The Northeast has 4 projects (19%), and the North, one project (5%).

Figure 24 and Figure 25 present the quantity and distribution of CDM projects with energy utilization per region.

**Figure 24.** Electricity generation from CDM projects per region

**Figure 25.** Distribution of CDM project with energy generation per region
### Table 5. List of CDM projects with energy utilization and/or energy generation

<table>
<thead>
<tr>
<th>Region</th>
<th>State</th>
<th>Ref# (UNFCCC)</th>
<th>Title</th>
<th>Status</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Amazonas</td>
<td>4211</td>
<td>Manaus Landfill Gas Project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td>Northeast</td>
<td>Bahia</td>
<td>1626</td>
<td>Feira de Santana Landfill Gas Project</td>
<td>Registered</td>
<td>ACM1+ACM2</td>
</tr>
<tr>
<td></td>
<td>Pernambuco</td>
<td>3958</td>
<td>CTR Candeias Landfill Gas Project</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>CTR-PE Landfill and LogiCarbon CDM Project</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>Rio Grande do Norte</td>
<td>NA</td>
<td>Natal Landfill Gas to Energy Project</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>Bahia</td>
<td>52</td>
<td>Salvador da Bahia Landfill Gas Management Project</td>
<td>Registered</td>
<td>AM2</td>
</tr>
<tr>
<td></td>
<td>Espírito Santo</td>
<td>137</td>
<td>Brazil MARCA Landfill Gas to Energy Project</td>
<td>Registered</td>
<td>AM3</td>
</tr>
<tr>
<td></td>
<td>Minas Gerais</td>
<td>NA</td>
<td>Uberlândia landfills I and II</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>Macaúbas Landfill Gas Project</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td>Rio de Janeiro</td>
<td>2548</td>
<td>Gramacho Landfill Gas Project</td>
<td>Withdrawn</td>
<td>AMG69+ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>Brazil NovaGerar Landfill Gas to Energy Project</td>
<td>Registered</td>
<td>AM3</td>
</tr>
<tr>
<td>Southeast</td>
<td></td>
<td>NA</td>
<td>CPA-Landfill gas recovery, energy generation and biogas distribution from CTR Santa Rosa</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td>São Paulo</td>
<td></td>
<td>91</td>
<td>Landfill Gas to Energy Project at Lara Landfill, Mauá, Brazil</td>
<td>Registered</td>
<td>AM3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>164</td>
<td>Bandeirantes Landfill Gas to Energy Project (BLFGE)</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>373</td>
<td>Sào João Landfill Gas to Energy Project (SJ)</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>911</td>
<td>ESTRE Itapevi Landfill Gas Project (EILGP)</td>
<td>Registered</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>Projeto de Gás de Aterro TECIPAR – PROGAT</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>Corpus/Araúna – Landfill Biogas Project.</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>Constroeste Landfill Gas to Energy Project</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>CGR Catanduva Landfill Gas Project</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>ESTRE Piratininga Landfill Gas Project</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
<tr>
<td>South</td>
<td>Paraná</td>
<td>NA</td>
<td>ESTRE Iguaçu Landfill Gas Project</td>
<td>At validation</td>
<td>ACM1</td>
</tr>
</tbody>
</table>
Table 5 provides a list of CDM projects that consider recovery and use of biogas, including region, state, UNFCCC reference number, project name, CDM cycle status, and applied methodology.

### 3.2.2 History of landfill energy generation in Brazil

This section includes public information stated in monitoring reports published in the UNFCCC website.

Of all registered Brazilian projects that include an electricity generation component from biogas in their PDDs, only two reported electricity generation, namely: Bandeirantes and São João landfill gas projects. Both are located in the Southeast Region, in São Paulo state. These two landfills report a generation of about 1.2 million MWh. Table 6 provides more detail on the reported generation for each site.

The Salvador da Bahia landfill also installed turbines for electricity generation, and the procedure of including this new component is reported in the Project Design Document (PDD). However, no data are available regarding the exact start date of the activities and/or generation.

#### Table 6. Landfill gas to electricity projects

<table>
<thead>
<tr>
<th>Region</th>
<th>State</th>
<th>Ref# (UNFCCC)</th>
<th>Title</th>
<th>Status</th>
<th>Electricity generated (MWh)</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast</td>
<td>São Paulo</td>
<td>164</td>
<td>Bandeirantes Landfill Gas to Energy Project (BLFGE)</td>
<td>Registered</td>
<td>755,700&lt;sup&gt;13&lt;/sup&gt;</td>
<td>January 2004 – December 2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>373</td>
<td>São João Landfill Gas to Energy Project (SJ)</td>
<td>Registered</td>
<td>476,900&lt;sup&gt;14&lt;/sup&gt;</td>
<td>March 2008 – May 2012</td>
</tr>
<tr>
<td>Northeast</td>
<td>Bahia</td>
<td>52</td>
<td>Salvador da Bahia Landfill Gas Management Project&lt;sup&gt;15&lt;/sup&gt;</td>
<td>Registered</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,232,600</td>
<td></td>
</tr>
</tbody>
</table>

<sup>12</sup> [http://cdm.unfccc.int/Projects/DB/DNV-CUK1134130255.56/view?cp=1](http://cdm.unfccc.int/Projects/DB/DNV-CUK1134130255.56/view?cp=1)
<sup>13</sup> [http://cdm.unfccc.int/Projects/DB/DNV-CUK1145141778.29/view](http://cdm.unfccc.int/Projects/DB/DNV-CUK1145141778.29/view)
<sup>14</sup> This project has installed plants from biogas generation capacity of approximately 20 MW. However, no reports of monitoring data available with electricity generation.
Recommended calculation methods to estimate emissions in Brazilian landfills

4.1 Introduction to Methane Generation Models

A landfill gas generation model is a tool that provides an estimation of generated methane or total landfill gas volume over time from a particular volume of waste. The purpose of a model is to describe in simple terms the complex changes during decomposition of waste in a landfill. It is based on the continuity of mass. McBean et al discuss this and the following figure reproduces their continuity of mass principle.

**Continuity of Mass Principle**

\[
\text{Refuse Placed} = \text{Mass leaving in leachate} + \text{Mass leaving in gas} + \text{Waste remaining} + \text{Mass transformed to other products}
\]

By combining simple models using this principle much can be learned about the way in which landfills operate. Methods for predicting gas generation began to appear in the early 1970's. Cossu et al stated the following definition of model types: where \( t \) = time, \( C \) = the amount of methane generated or degradable substrate. The greatest absolute exponent \( n \) of the dependent variable is called the order of the model (i.e. order of kinetics).

All of the assumptions inherent in a theoretical model are not met in any real world landfill. If these complex models are thus limited by the quality of the input data available to them, then perhaps there is room for a simpler, empirical model, both as to transport and generation. Such an empirical model must be based upon
some real-world data, and it certainly would be restricted in use to the types of landfills used in generating the data base upon which it was built. Nevertheless, it might still be useful in predicting average emissions, from which we might estimate worst-case emissions for purposes of doing risk assessments.

Numerous models have been proposed to predict the amount of methane produced throughout the lifetime of a landfill. These models generally fall into four different categories: zero-order, first-order, multi-phase, and second-order (Coops et al., 1995).

### 4.1.1 Zero-Order Models

In zero-order models, landfill gas formation from a certain amount of waste is assumed to be constant with time. A zero order kinetics means that a small increment (positive or negative) of C does not influence the rate of substrate decay or biogas production. In other words, a zero order model indicates that the rate of methane generation is independent of the amount of substrate remaining or of the amount of biogas already produced.

This type of model is used for estimating national and global emissions with the assumption that there is no major change in waste composition or the amount of material landfilled. An example of a zero-order model is the EPA Regression Model (Peer et al., 1993). This model is based solely on a linear correlation of methane recovery and refuse mass. Moisture levels, decomposability of the refuse, and other factors are not considered. The assumed methane generation potential of the refuse is estimated as 0.023–0.061 grams of methane per gram of wet refuse. This model predicts US methane emissions from landfills to be 2–6 Tg assuming an annual placement of 100 Tg refuse.

### 4.1.2 First-Order Models

First-order models include the effect of age in methane generation. Landfill gas formation in a certain amount of waste is assumed to decay exponentially with time. Modifications of simple first-order models have also been made to include the build-up of the methanogenic phase and temperature dependency (Coops et al., 1995).

First-order models are by far the most commonly used landfill gas generation model used today. The EPA's LandGEM is a first order model that is considered the LFG industry standard, and must be used to estimate LFG emissions from U.S. landfills that are regulated by the EPA, under the Clean Air Act (CAA). The LandGEM software is available at the EPA's Technology Transfer website at: http://www.epa.gov/ttn/catc/products.html#software15. Other EPA models used by the landfill gas industry include gas collection and control system cost estimation models, such as E-PLUS and LFGCost, that use the LandGEM to estimate landfill gas generation as a component of the cost models.

---

15 Landfill Gas Emissions Model (LandGEM), version 3.02. XLS file is the LandGEM Model
4.1.3 Multi-Phase Models

Numerous first-order models are combined to express methane generation from different fractions of the refuse. These are called “multi-phase models” (Coops et al., 1995). Multi-phase models should more closely represent what happens in a full-scale landfill. The fractions of waste are defined by the level of degradability of various components of the waste; such as:

- readily degradable,
- moderately degradable,
- slowly degradable, and
- inert.

An example of a multi-phase model is the EMCON Kinetics Model (Augenstein & Pacey, 1991; Augenstein, 1992). In this model, there is a lag time in which no methane is generated. This is followed by a phase of constant rate increase, followed by an exponential decrease in methane production. A useful term in this model is “t_{1/2}” which refers to the time from placement of the waste to the time when gas generation equals half the estimated yield. Estimates by Soriano (as described in Augenstein & Pacey, 1991) imply values of t_{1/2} of 10–25 years for ‘dry’ regions of the United States, 5–10 years for regions with a medium level of precipitation, and 2–5 years for wet regions of the country. The actual time that a landfill generates methane may be several multiples of t_{1/2} depending on the actual shape of the generation curve.

4.1.4 Second-Order Models

Second-order models have also been proposed to predict methane emissions based on the complicated chemistry and microbiology of methane synthesis. Since a large number of reactions are involved, all with different reaction rates, second-order kinetics are used to predict total methane generation. An example of this is the model by Swarbrick et al. (1995). This model uses both physical and biochemical parameters, but with only two rate-limiting steps. A more complex model by Young (1995) models the populations of methanogenic bacteria, treating the earlier processes as being dependent solely on substrate and nutrient availability.

4.1.5 Which model is the most accurate?

Peer et al. (1993) concluded that the most important factor in the calculation was the assumed methane potential of the refuse (L_0) and not the actual mathematical model used to obtain the estimates of methane emissions.

Coops et al. (1995) validated all these models by comparing predicted values to field data from nine landfills in the Netherlands. They concluded that the first-order, second-order, and multi-phase models were all similar in describing landfill gas formation, although the multi-phase model was slightly more accurate than the others in predicting actual methane emissions. The zero-order model was the most unreliable.
Discrepancies between values predicted by the models and actual field data were due to uncertainties in waste quantity and composition, the heterogeneity of the landfill microenvironment, and uncertainties in the actual recovery efficiency of the methane collection system rather than from differences in the models themselves.

### 4.2 Important Calculation Factors

#### 4.2.1 Methane Generation Potential (L₀)

The methane generation potential, L₀, represents the total amount of methane that one metric ton of waste is expected to generate over its lifetime.

The theoretical maximum production of landfill gas (LFG) assumes adequate moisture is present to complete the chemical reaction. In a conventional “dry” landfill, sufficient moisture does not exist to complete the chemical reaction. This is a result of deliberate efforts to minimize moisture infiltration. Typically, even bioreactor landfills have a difficult time adding and controlling moisture to optimize organic degradation. This difficulty can be attributed to preferential flow paths (i.e., inconsistencies in MSW composition that cause moisture to be distributed unevenly), plastic bags that shield organics from moisture, and internal landfill temperatures that reduce the speed of the chemical reaction. The result of either of these factors (LFG generation that peaks early and then tapers off or less moisture than needed to complete degradation) is that a conventional landfill is likely to produce LFG at levels below the theoretical maximum.

The theoretical methane (CH₄) generation capacity (L₀) can be determined by a stoichiometric method, which is based on a gross empirical formula representing the chemical composition of the waste. If a waste contains carbon, hydrogen, O₂, nitrogen and sulfur (represented by CaH₅O₇N₅S₅), its decomposition to gas is shown as:

\[
\text{C}_a\text{H}_b\text{O}_c\text{N}_d\text{S}_e + \frac{(4a-b-2c+3d-2e)}{4} \text{H}_2\text{O} \rightarrow \\
(4a+b-2c-3d-2e) \text{CH}_4 + (4a-b+2c+3d+2e) \text{CO}_2 + d \text{NH}_3 + e \text{H}_2\text{S}
\]

The value of L₀ is most directly proportional to the waste’s cellulose content. The theoretical CH₄ generation rate increases as the cellulose content of the refuse increases. If the landfill conditions are not favorable to methanogenic activity, there would be a reduction in the theoretical value of L₀. This implies that the theoretical (potential) value of CH₄ generation may never be obtained. The obtainable value for the refuse (or specific waste components) is approximated by performing overall biodegradability tests on the waste under conditions of temperature, moisture, nutrient content, and pH likely to exist in the landfill.
4.2.2 Generation Rate Constant (k)

Another important factor in some methane generation models is the CH₄ generation rate constant, k, which estimates how rapidly the CH₄ production rate falls after the waste has been placed (since the method assumes the rate is at its maximum upon placement).

The value of k is strongly influenced by:

- temperature,
- moisture content,
- availability of nutrients, and
- pH.

CH₄ generation increases as the moisture content increases up to a level of 60 to 80%, at which the generation rate does not increase. Once these constants have been estimated, the rate of waste placement and the time in the landfill life cycle determine the estimated gas emission rate.

4.3 U.S.EPA Gas Estimations Methods

There are a variety of methods, ranging from desktop estimates to actual field tests, as described below. Because the cost of the estimates is significantly higher for field methods without a corresponding increase in reliability, it is recommended that LFG generation estimated be conducted using a desktop model, such as the EPA's LandGEM.

4.3.1 LandGEM Model (U.S.EPA Software)

The Landfill Air Emissions Model (LandGEM), Beta version is PC-based software for estimating emissions of methane, carbon dioxide, non-methane organic compounds (NMOC), and hazardous air pollutants from municipal solid waste landfills. The mathematical model used in landfill is based on a first order decay equation that can be run using site-specific data supplied by the user for the parameters needed to estimate emissions or, if data are not available, using default value sets included in landfill.

The LFG generation model requires a few basic inputs such as the landfill’s dates of operation and the amount of waste currently in place in the landfill. The model employs a first-order exponential decay function. This function is based on the idea that the amount of LFG generated from solid waste reaches a peak after a certain time lag for methane generation. The model assumes a one-year time lag between placement of waste and LFG generation. The model also assumes that for each unit of waste, LFG generation decreases exponentially (after the one-year time lag) as the organic fraction of the waste is consumed.

For sites with known (or estimated) year-to-year solid waste acceptance rates, the model estimates the LFG generation rate for a given year using the following equation:

$$Q_M = \sum_{i=1}^{n} 2kL_0M_i(e^{-kt})$$
where:
\[ Q_M = \text{maximum expected LFG generation flow rate (m}^3/\text{yr)}; \]
\[ \sum_{i=1}^{n} = \text{sum from opening year +1 (i=1) through year of projection (n)}; \]
\[ k = \text{methane generation rate constant (1/yr)}; \]
\[ L_0 = \text{methane generation potential (m}^3/\text{Mg)}; \]
\[ M_i = \text{mass of solid waste disposed in the } i\text{th year (Mg)}; \]
\[ t_i = \text{age of the waste disposed in the } i\text{th year (years)}. \]

The above equation is used to estimate LFG generation for a given year from all waste disposed up through that year. One may develop multi-year projections by varying the projection year and re-applying the equations. The point of maximum LFG generation normally occurs in the closure year or the year following closure (depending on the disposal rate in the final years).

### 4.3.2 \( L_0 \) and \( k \) Defaults Values in Landfills

Theoretical and obtainable \( L_0 \) values have been reported in literature to range from approximately 6 to 270 m\(^3\) CH\(_4\) per metric ton of waste for municipal landfills. Values of \( k \) obtained from literature, laboratory simulator results, and back-calculated from measured gas generation rates range from 0.003/yr to 0.21/yr.

According the USEPA standards, there are two sets of default values to be applied when using the LandGEM to estimate landfill gas generation for regulatory compliance purposes. One set, the Clean Air Act (CAA) set, is based on requirements of the New Source Performance Standards (NSPS) controlling emissions to the atmosphere from new municipal solid waste landfills or federal emission guidelines for emissions from existing landfills. This set of default values produces conservative emission estimates that can be used to determine the applicability of Federal regulations or guidelines to the landfill being evaluated. The CAA default parameters are current as of September 1997. The CAA requires that a landfill located in an arid area (less than 25 inches (635 mm) of precipitation per year) use a \( k \) value of 0.02 1/yr and a \( L_0 \) value of 170 m\(^3\)/Mg of refuse. A \( k \) value of 0.04 1/yr and a \( L_0 \) value of 170 m\(^3\)/Mg of refuse must be used for landfills located in wetter areas (that experience at least 25 inches (635 mm) per year of precipitation).

The other set of values, the AP-42 set, is based on emissions factors in EPA's guidance document, Compilation of Emission Factors, Fifth Edition, AP-42. This set of default values is less conservative (i.e., yields lower LFG generation rate estimates) than the CAA set and can be used to produce typical emission estimates in the absence of site-specific test data. The AP-42 default parameters are current as of September 1997 and are applicable to most landfills in the United States. AP-42 recommends that a landfill located in an arid area (less than 25 inches (635 mm) of rainfall per year) use a \( k \) value of 0.02 1/yr and a \( L_0 \) value of 100 m\(^3\)/Mg of refuse.

If \( L_0 \) and \( k \) terms were known with certainty, the first order decay model would predict methane generation relatively accurately; however, the values for \( L_0 \) and \( k \) are thought to vary widely, and are difficult to estimate accurately for a particular landfill.
Author Name

Observed ranges and recommended values for \( L_0 \) and \( k \) values are presented in Table 7. Note that the \( L_0 \) (total amount of LFG generated) remains the same under wet and medium moisture climatic conditions, but decreases under dry climatic conditions. The \( k \) values (rate of LFG generation) are different in each climate category, with dry climates generating gas more slowly.

Because of the uncertainty in estimating \( L_0 \) and \( k \), gas flow estimates derived from the first order decay model should also be bracketed by a range of model ± 50 percent, unless the model can be calibrated with actual LFG flow data from a reasonably comprehensive gas collection system.

### 4.3.3 Correcting for Collection Efficiency

Before gas generation estimates are used to size a collection/energy recovery system, it is necessary to correct for landfill gas collection efficiency, which is the portion of generated LFG that is captured by the system. There are several factors which affect the overall collection efficiency of a LFG extraction system, which can vary from less than 50 to over 90\%. The most important factor is wellfield coverage of the refuse mass, as measured by well spacing and depth. The permeability of the landfill's cover layer is another important factor that influences how much of the landfill gas generated will escape to the atmosphere; however, a portion of the landfill gas will escape through the cover of even the most tightly constructed and controlled collection system. Other site-specific factors also affect collection efficiency, such as bottom and side liners, leachate and water levels, and meteorological conditions.

Multiplying the total landfill gas generation estimated by a collection efficiency of 60 to 85\% for comprehensive landfill gas collection systems should yield a reasonable estimate of the LFG available for energy recovery.

### 4.3.4 LFG Energy Benefits Calculator and LFGCost (U.S.EPA Software)

The Energy Project Landfill Gas Utilization Software (E-PLUS) and the Landfill Gas Cost Estimation Model are U.S.EPA software which allow users to determine the economic and environmental feasibility of a potential LFG project and to perform an initial financial and environmental benefits analysis. Its intuitive interface makes it easy to use. LFG Energy Benefits Calculator and LFGCost use the same model equation as the LandGEM Model. The software can be found on the U.S. EPA website: [http://www.epa.gov/lmop/publications-tools/index.html](http://www.epa.gov/lmop/publications-tools/index.html)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Suggested Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_0 ) (m³/t)</td>
<td>0 - 187</td>
<td>Wet Climate: 62-140, Medium Climate: 62-140, Dry Climate: 47-125</td>
</tr>
<tr>
<td>( k ) (1/year)</td>
<td>0.003-0.3</td>
<td>Wet Climate: 0.05-0.20, Medium Climate: 0.03-0.10, Dry Climate: 0.01-0.05</td>
</tr>
</tbody>
</table>
4.4 CDM Tool

The Tool to determine avoided methane emissions in a solid waste disposal site was developed in order to calculate baseline emissions resulted from waste that, in the absence of the project activity, would be disposed in solid waste disposal sites (SWDS). Emission reductions are calculated with a first-order decay model. While this tool is intended for avoided waste at disposal areas, it is still very useful to calculate the amount of methane generated from landfilled waste in the case of the proposed project.

The tool provides the following procedure to determine $BE_{CH_4,SWDS,y}$:

$$BE_{CH_4,SWDS,y} = \varphi \cdot (1 - f) \cdot GWP_{CH_4} \cdot (1 - OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF \cdot \sum_{x=1}^{y} \sum_{j} W_{j,x} \cdot DOC_j \cdot e^{-k_j(y-x)} \cdot (1 - e^{-f})$$

Where:

- $BE_{CH_4,SWDS,y}$ = Methane emissions avoided during the year $y$, with prevention of waste destination at the SWDS during the period from the start of the project activity until the end of the year $y$ (tCO2e);
- $\varphi$ = Correction factor of the model, for model uncertainty consideration (0.9);
- $f$ = Methane fraction captured at the SWDS and flared, incinerated or used otherwise;
- $GWP_{CH_4}$ = Global Warming Potential of methane, valid for the relevant commitment period;
- $OX$ = Oxidation factor (reflecting the volume of methane in the SWDS that is oxidized on soil or other material used for covering of waste);
- $F$ = Methane fraction in gas at SWDS (volume fraction) (0.5);
- $DOC_f$ = Fraction of Degradable Organic Carbon subject to decay;
- $MCF$ = Methane correction factor;
- $W_{j,x}$ = Amount of organic waste type $j$ not disposed at SWDS in the year $x$ (tons);
- $DOC_j$ = Fraction of Degradable Organic Carbon (per weight) in waste type $j$;
- $k_j$ = Decay rate for waste type $j$;
- $j$ = Waste type (rate);
- $x$ = Year as of the landfill started receiving waste [x varies from the landfill’s first operational year (x=1) to the year emissions were calculated (x=y)] Note: this definition is a correction of the Tool as per ACM0001;
- $y$ = Year for which methane emissions were calculated.

When methane in the SWDS is collected (i.e.: due to safety regulations) and flared, incinerated or used otherwise, the baseline emissions are adjusted to the fraction of methane captured at SWDS.

---

16 Note that, in this Project case, “avoided methane emissions” mean methane emissions produced in the landfill. The period considered here will thus be from the landfill’s opening to closure.

17 Oonk et al. (1994) validated some landfill gas models based on 17 landfill gas projects carried out. The average relative error of multi-phase models was estimated at 18%. Given the uncertainties related to the model and in order to have a conservative estimation of the emission reductions, a 10% discount is applied to the results of the model.
4.5 IPCC

Emissions from sanitary and controlled landfills, as well as from dumpsites, are estimated using the (revised) IPCC 1996 first-order decay method, published in the IPCC 2000 Good Practice Guidance. Known as \textit{Tier 2}, this method considers that CH₄ emissions persist along a period of years after disposal of the waste (IPCC, 2000). Some data are necessary to apply the method, such as climate (annual temperature and rainfall averages), amount of waste, composition of waste, quality of the landfill operation, and amounts of CH₄ recovered and oxidized.

According to the IPCC 2000 Good Practice Inventory Guidance, the following equation is used for estimating the CH₄ emissions under the first-order decay method (\textit{Tier 2}):

\[ Q = \sum x \left\{ [(A \cdot k \cdot MSWT(x) \cdot MSWF(x) \cdot L_0(x)) \cdot e^{-k(x-t)}] - R(x) \right\} \cdot (1 - OX) \]

\[ Q \] = Amount of methane generated per year [GgCH₄/yr]
\[ A \] = Normalization factor for sum [adimensional]
\[ k \] = Constant CH₄ generation rate [1/yr]
\[ MSWT(x) \] = Total amount of urban solid waste generated in the year x [GgMSW/yr]
\[ MSWF(x) \] = Fraction of MSW destined to landfill in the year x [adimensional]
\[ L_0(x) \] = Methane generation potential [GgCH₄/GgMSW]
\[ T \] = Inventory year [yr]
\[ X \] = Years in which data were considered

Definition of A:

\[ A = \frac{1 - e^{-k}}{k} \]

Definition of L₀:

\[ L_0(x) = MCF(x) \cdot DOC(x) \cdot DOCf \cdot F \cdot 16/12 \]

Where:

\[ MCF(x) \] = Methane correction factor related to disposal site management [adimensional]
\[ DOC(x) \] = Degradable Organic Carbon gC/gMSW⁻¹
\[ DOCf \] = Decaying DOC fraction [adimensional]
\[ F \] = Methane fraction in biogas [adimensional]
\[ 16/12 \] = Carbon (C) to methane (CH₄) conversion ratio [adimensional]
Definition of \( \text{DOC}(t) \)

\[
\text{DOC}(t) = (0.17 \cdot A) + (0.26 \cdot B) + (0.45 \cdot C) + (0.47 \cdot D) + (0.07 \cdot E) + (0.11 \cdot F) + (0.29 \cdot G) + (0.33 \cdot H) + (0.13 \cdot I)
\]

**Table 8. Emission factors related to waste composition**

<table>
<thead>
<tr>
<th>Corresponding fraction of waste</th>
<th>Emission factor (IPCC 2006) [gC/gMSW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Paper and cardboard</td>
<td>0.17</td>
</tr>
<tr>
<td>B - Textiles</td>
<td>0.26</td>
</tr>
<tr>
<td>C - Food waste</td>
<td>0.45</td>
</tr>
<tr>
<td>D - Wood</td>
<td>0.47</td>
</tr>
<tr>
<td>E - Rubber and leather</td>
<td>0.07</td>
</tr>
<tr>
<td>F - Plastics</td>
<td>0.11</td>
</tr>
<tr>
<td>G - Metals</td>
<td>0.29</td>
</tr>
<tr>
<td>H - Glass</td>
<td>0.33</td>
</tr>
<tr>
<td>I - Others</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Where:

\[
Q_E = [Q-R] \cdot (1-OX)
\]

Where:

- \( Q_E \) = Amount of methane emitted in the year [GgCH\(_4\)/yr]
- \( R \) = Methane recovery [GgCH\(_4\)/yr]
- \( OX \) = Oxidation factor [adimensional]
The IPCC estimation method was chosen to estimate biogas at the different final disposal sites in Brazil. The main reason for choosing this method was availability of information; besides, this method is consistent with the method used to carry out inventories and national GHG emission communications.

According to the adopted method, MGM gathered the necessary information from ABRELPE to estimate methane emissions in Sanitary Landfills, Controlled Landfills and Dumpsites, for each state and region. These data are described as follows.

5.1 Constant CH₄ generation rate – $k$ and Normalization factor for sum – $A$

The constant CH₄ generation rate set in the first-order decay method is related to the necessary time for the amount of Degradable Organic Carbon (DOC) in the disposed waste mass to decrease upon decomposition.

The $k$ applicable to solid waste disposal sites is obtained from some factors related to waste composition and the conditions of the region the landfill or dumpsite is located, such as: waste composition, average annual temperature, and evapotranspiration potential (IPCC, 2000).

National data for $k$ or $A$ were not identified. Due to this, the default for $k$ for each fraction of one waste component in boreal and temperate zones was applied, as per the IPCC (2006) method, according to the following Table 9.

According to the Table 9, the choice of the default for $k$ requires obtaining the following national information: Mean Annual Temperature – MAT, Mean Annual Precipitation – MAP, and Potential Evapotranspiration – PET. These data are provided as follows.
Table 9. Default of $k$ for each fraction of waste component type
Source: IPCC 2006, V5 – Chapter 3: Solid Waste Disposal

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Climate zone</th>
<th>Boreal and temperate</th>
<th>Tropical</th>
<th>MAT $\leq 20^\circ\text{C}$</th>
<th>MAT $\leq 20^\circ\text{C}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dry (MAP/PET $&lt; 1$)</td>
<td>Wet (MAP/PET $&gt; 1$)</td>
<td>Dry (MAP/PET $&lt; 1000\text{mm}$)</td>
<td>Wet (MAP/PET $\geq 1000\text{mm}$)</td>
</tr>
<tr>
<td></td>
<td>Default</td>
<td>Range</td>
<td>Default</td>
<td>Range</td>
<td>Default</td>
</tr>
<tr>
<td>Paper/textiles</td>
<td>0.04</td>
<td>0.03 - 0.05</td>
<td>0.06</td>
<td>0.05 - 0.07</td>
<td>0.045</td>
</tr>
<tr>
<td>Wood/straw waste</td>
<td>0.02</td>
<td>0.01 - 0.03</td>
<td>0.03</td>
<td>0.02 - 0.04</td>
<td>0.025</td>
</tr>
<tr>
<td>Other (non-food) organic putrescible*</td>
<td>0.05</td>
<td>0.04 - 0.06</td>
<td>0.1</td>
<td>0.06 - 0.1</td>
<td>0.065</td>
</tr>
<tr>
<td>Garden and park waste</td>
<td>0.05</td>
<td>0.04 - 0.06</td>
<td>0.1</td>
<td>0.06 - 0.1</td>
<td>0.065</td>
</tr>
<tr>
<td>Food waste</td>
<td>0.06</td>
<td>0.05 - 0.08</td>
<td>0.185</td>
<td>0.1 - 0.2</td>
<td>0.085</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>0.06</td>
<td>0.05 - 0.08</td>
<td>0.185</td>
<td>0.1 - 0.2</td>
<td>0.085</td>
</tr>
<tr>
<td>Bulk waste</td>
<td>0.05</td>
<td>0.04 - 0.06</td>
<td>0.09</td>
<td>0.08 - 0.1</td>
<td>0.065</td>
</tr>
</tbody>
</table>

* Note: leather, natural rubber and diapers were considered as “Other (non-food) organic putrescible”

5.1.1 Mean Annual Temperature – MAT

The Mean Annual Temperature (MAT) is the average of mean monthly temperatures, which are the sum of daily compensated mean temperatures divided by the number of days in the month (CETESB, 2010).

The Figure 26 shows the MAT data in Brazil for the 1961 – 1990 period.

5.1.2 Mean Annual Precipitation – MAP

Mean Annual Precipitation – MAP – is the sum of annual precipitation during a given period, divided by the number of years. The different rainfall zones of Brazil for the 1961 – 1990 period are shown in the Figure 27.

All Brazilian regions, except the South, have a MAT of over 20$^\circ\text{C}$, and a MAP of over 1,000mm/yr. In the Northeast, part of the territory has a MAP of less than 1,000mm/yr. The Northeastern states with this characteristic were manually identified by overlapping the regional and MAP maps.
Figure 26. Mean compensated temperature in Brazil – MAT
Source: (CETESB, 2010)

Figure 27. Rainfall intensity in Brazil – MAP
Source: (CETESB, 2010)
5.1.3 Potential Evapotranspiration – PET

The PET represents the potential water that can return to the atmosphere via evapotranspiration, being evaporation the maximum loss of water to the atmosphere, in form of vapor, which occurs with growing vegetation without water restriction on soil (MAPA\textsuperscript{19}).

The South Region has a MAT lower than 20°C, with an average MAP of 1,582.2 mm/year\textsuperscript{20} and an average PET of 980.2 mm/year\textsuperscript{21} (CETESB, 2010). The MAP/PET relation in the South Region equals 1.6 – i.e., greater than 1. Table 6 of IPCC 2006 shows the default $k$ to be employed for Boreal Climate – Temperate, Wet.

5.1.4 Total Municipal Solid Waste – MSW\textsubscript{T}(t) and Fraction of MSW sent to SWDS – MSW\textsubscript{F}(t)

The product of (MSW\textsubscript{T}(t) \cdot MSW\textsubscript{F}(x)) results into the amount of MSW sent to Sanitary Landfills, Controlled Landfills, and Dumpsites.

ABRELPE provided data for the 2009 – 2011 period for estimation of the emissions. For the adopted method, however, the quantities were extrapolated for the period from 2012 to 2039.

5.1.5 Methane Generation Potential – L\textsubscript{0}(x)

To estimate the Methane Generation Potential – L\textsubscript{0}(x), it is necessary to understand the variables and emission factors that were employed for the calculation.

Therefore, the following are the data and emission factors that correspond to the variables used for determination of L\textsubscript{0}(x), namely: MCF\textsubscript{(x)}, DOC\textsubscript{(x)}, DOC\textsubscript{F} and F.

5.1.5.1 Methane Correction Factor – MCF(x)

Waste elimination practices vary in control, waste placement and site management. The Methane Correction Factor (MCF) represents that non-managed disposal sites produce less methane as from a certain amount of anaerobically-generated waste. At unmanaged places, a larger fraction of waste decomposes anaerobically at the top layer. At unmanaged sites with deep disposal and/or a high water table, the anaerobic-degrading waste fraction must be lower than at shallow sites. Controlled semi-anaerobic sites are passively administrated to introduce air into the waste layer and create a semi-aerobic interior environment. The MCF related to solid waste management is specific for these areas and must be taken as the waste management correction factor, which reflects the management feature that encompasses it (IPCC, 2006).

\textsuperscript{19} MAPA – Ministério da Agricultura, Pecuária e Abastecimento (Ministry of Agriculture, Livestock and Supply), Available in: http://www.agritempo.gov.br/modules.php?name=Encyclopedia&op=content&tid=94, date 02/07/2012


The IPCC 2006 classification was used. These data are provided in the following Table 10.

According to the Table 11, the data used for this estimation.

**Table 10.** Methane correction factors
Source: IPCC 2006, V5 – Chapter 3: Solid Waste Disposal

<table>
<thead>
<tr>
<th>SWDS Classification and Methane Correction Factors (MCF)</th>
<th>Default Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Managed – anaerobic¹</td>
<td>1.0</td>
</tr>
<tr>
<td>Managed – semi-aerobic²</td>
<td>0.5</td>
</tr>
<tr>
<td>Unmanaged³ – deep (&gt;5 m waste) and /or high water table</td>
<td>0.8</td>
</tr>
<tr>
<td>Unmanaged⁴ – shallow (&lt;5 m waste)</td>
<td>0.4</td>
</tr>
<tr>
<td>Uncategorized SWDS⁵</td>
<td>0.6</td>
</tr>
</tbody>
</table>

1 Anaerobic managed solid waste disposal sites: These must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) leveling of the waste.

2 Semi-aerobic managed solid waste disposal sites: These must have controlled placement of waste and will include all of the following structures for introducing air to waste layer: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system.

3 Unmanaged solid waste disposal sites – deep and/or with high water table: All SWDS not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 meters and/or high water table at near ground level. Latter situation corresponds to filling inland water, such as pond, river or wetland, by waste.

4 Unmanaged shallow solid waste disposal sites: All SWDS not meeting the criteria of managed SWDS and which have depths of less than 5 meters.

5 Uncategorized solid waste disposal sites: Only if countries cannot categorize their SWDS into above four categories of managed and unmanaged SWDS, the MCF for this category can be used.

Sources: IPCC (2000); Matsufuji et al. (1996)

**Table 11.** MCF for Sanitary and Controlled Landfill, and Dumpsite

<table>
<thead>
<tr>
<th>Site</th>
<th>Emission factor (default)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanitary Landfill</td>
<td>1.0</td>
</tr>
<tr>
<td>Controlled Landfill</td>
<td>0.8</td>
</tr>
<tr>
<td>Dumpsite</td>
<td>0.4</td>
</tr>
</tbody>
</table>
5.1.5.2 Degradable Organic Carbon – DOC(x)

Degradable Organic Carbon (DOC) is the organic carbon of waste that is accessible to biochemical decom-
position. It must be represented as Gg C per Gg waste. With large amounts of waste, DOC is estimated bases on
waste composition and can be calculated from a weighted average of the degradable carbon content in several
components (types of waste/materials) of the waste flow (IPCC 2006).

The equation shown in section 4.5 is used in order to determine DOC\(_x\), as per the IPCC 2006 method, plus
the following waste composition in Table 12.

5.1.5.3 Fraction of Degradable Organic Carbon which Decomposes – DOCf

The Fraction of Degradable Organic Carbon Which Decomposes (DOCf) is an estimate of the fraction of
carbon that is ultimately degraded and released from SWDS, and reflects the fact that some degradable organic
carbon does not degrade, or degrades very slowly, under anaerobic conditions in the SWDS. The recommended
default value for DOCf is 0.5 (under the assumption that the SWDS environment is anaerobic and the DOC
values include lignin, see Table 2.4 for default DOC values) (Oonk and Boom, 1995; Bogner and Matthews
2003). DOCf value is dependent on many factors like temperature, moisture, pH, composition of waste, etc.
(IPCC 2006).

The amount of DOC leached from the SWDS is not considered in the estimation of DOCf. Generally the
amounts of DOC lost with the leachate are less than 1% and can be neglected in the calculations (IPCC 2006).

The value adopted for estimation was 0.5.

**Table 12. Degradable Organic Carbon – DOC(x)**

<table>
<thead>
<tr>
<th>Corresponding waste fraction</th>
<th>Emission factor (IPCC 2006) [gC/gMSW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Paper and cardboard</td>
<td>0.17</td>
</tr>
<tr>
<td>B - Textiles</td>
<td>0.26</td>
</tr>
<tr>
<td>C - Food waste</td>
<td>0.45</td>
</tr>
<tr>
<td>D - Wood</td>
<td>0.47</td>
</tr>
<tr>
<td>E - Rubber and leather</td>
<td>0.07</td>
</tr>
<tr>
<td>F - Plastics</td>
<td>0.11</td>
</tr>
<tr>
<td>G - Metals</td>
<td>0.29</td>
</tr>
<tr>
<td>H - Glass</td>
<td>0.33</td>
</tr>
<tr>
<td>I - Others (e.g., ash, dirt, dust, soil, electronic waste)</td>
<td>0.13</td>
</tr>
</tbody>
</table>
5.1.5.4 Fraction of methane in biogas – F

Waste in SWDS generates a gas with approximately 50% CH₄. Only material including substantial amounts of fat or oil can generate gas with substantially more than 50% CH₄. The use of the IPCC default value for the fraction of CH₄ in landfill gas (0.5) is therefore encouraged (IPCC 2006).

5.1.6 Recovered methane – R

Brazilian standard NBR – 13.896/97, item 5.3 on gas emissions, recommends that “Every landfill should be designed so as to minimize gas emissions and promote proper collection and treatment of potential emanations”. With this recommendation, the standard sets a directive rather than a legal obligation. Consequently, landfill projects expect open flaring of biogas, with flares normally installed at the exit of the leachate draining well, which is adequate to reduce methane emissions and odors as well (CETESB 2010).

The first CDM projects established a baseline of 20% of methane flaring. Magalhães et al, 2010 states that such estimation is over-estimated. More recent projects revised this consideration, always tending to lower amounts than those firstly employed (CETESB 2010).

However, for the estimates, R was considered as zero for all regions and states.

5.1.7 Oxidation factor – OX

The oxidation factor (OX) reflects the amount of CH₄ from SWDS that is oxidized in the soil or other material covering the waste (IPCC 2006).

CH₄ oxidation is by methanotrophic micro-organisms in cover soils and can range from negligible to 100% of internally produced CH₄. The thickness, physical properties and moisture content of cover soils directly affect CH₄ oxidation (Bogner and Matthews, 2003 apud IPCC 2006).

Studies show that sanitary, well-managed SWDS tend to have higher oxidation rates than unmanaged dump sites (IPCC 2006).

The OX values of the following Table 13 were used to estimate the emissions.

<table>
<thead>
<tr>
<th>Type of Site</th>
<th>Oxidation Factor (OX) Default Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Managed¹, unmanaged and uncategorized SWDS</td>
<td>0</td>
</tr>
<tr>
<td>Managed covered with CH₄ oxidizing material²</td>
<td>0.1</td>
</tr>
</tbody>
</table>

¹ Managed but not covered with aerated material
² Examples: soil, compost

Table 13. Oxidation Factor

Source: IPCC 2006, V5 – Chapter 3: Solid Waste Disposal
5.2 Results of estimation modeling of GHG emissions in the 2009-2039 period per region and state

The following are the results of estimated GHG emissions associated to waste disposal according to the different types of disposal. The results are displayed according to region and state.

To make the estimation, in addition to using the parameters stated above, some assumptions on time variation over the type of final disposal were also made. For this, we used the 2009-2011 ABRELPE data, which provides some direction on how this distribution varies over time. Additionally, during the years of the modeling exercise, the assumed percentage of waste disposed in sanitary landfills shows a small increase, while dumpsites and controlled landfills have less participation because of a stricter legislation and the economic growth in Brazil.

More information can be found in the calculation spreadsheets prepared for each region, attached to this report.

Table 14 summarizes GHG emission estimates per region according to final waste disposal, itemized by type, and final disposal for the analyzed 2009-2039 period. The results indicate that over this 30-year period waste disposal could produce about 892 million CO₂e, which represents an average of 29.7 million tons/yr.

The upper section of Figure 28 shows estimated percentage of GHG emissions per region during the analyzed period. The Southeast Region is estimated to generate about 60% of the emissions in Brazil, followed by the Northeast, with 18%. The Mid-West and South regions would generate about 8% each, and finally, the North Region would be responsible for about 6%.

The bottom section of Figure 28 shows how GHG emissions would be distributed according to the type of final disposal and region. It should be noted that 69% of the emissions in sanitary landfills would occur in sites in the Southeast Region, while the Northeast Region would have the highest share in dumpsite emissions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Sanitary Landfill (tCO₂e)</th>
<th>Controlled Landfill (tCO₂e)</th>
<th>Dumpsite (tCO₂e)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>27,176,948</td>
<td>19,293,712</td>
<td>11,207,468</td>
<td>57,678,127</td>
</tr>
<tr>
<td>Northeast</td>
<td>81,359,268</td>
<td>51,720,052</td>
<td>23,268,194</td>
<td>156,347,515</td>
</tr>
<tr>
<td>Mid-West</td>
<td>31,972,185</td>
<td>29,748,332</td>
<td>7,131,202</td>
<td>68,851,719</td>
</tr>
<tr>
<td>Southeast</td>
<td>448,987,315</td>
<td>65,900,593</td>
<td>22,564,710</td>
<td>537,452,618</td>
</tr>
<tr>
<td>South</td>
<td>61,264,397</td>
<td>7,954,859</td>
<td>2,693,376</td>
<td>71,912,632</td>
</tr>
<tr>
<td>Total</td>
<td>650,760,113</td>
<td>174,617,547</td>
<td>66,864,950</td>
<td>892,242,611</td>
</tr>
</tbody>
</table>
**Figure 28.** GHG emission distribution per region and type of final disposal, 2009-2039

**Figure 29.** Average annual GHG emissions per region
Figure 29 provides the annual GHG emission average per region and type of final disposal. It is clear that most of the emissions from sanitary landfills are generated in the Southeast Region.

The following Table 15 and Table 19 present the results per region and state. Each table is accompanied by the respective percentage distribution graph per state/region.

**Table 15. GHG emissions results per state – North Region (2009 – 2039)**

<table>
<thead>
<tr>
<th>States</th>
<th>Sanitary Landfill</th>
<th>Controlled Landfill</th>
<th>Dumpsite</th>
<th>Total Emissions (tCO₂e)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emissions (tCO₂e)</td>
<td>Emissions (tCO₂e)</td>
<td>Emissions (tCO₂e)</td>
<td>Total Emissions (tCO₂e)</td>
<td></td>
</tr>
<tr>
<td>North Region</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acre</td>
<td>1,965,584</td>
<td>663,143</td>
<td>340,311</td>
<td>2,969,038</td>
<td>5.1%</td>
</tr>
<tr>
<td>Amapá</td>
<td>1,822,754</td>
<td>1,070,069</td>
<td>465,931</td>
<td>3,358,755</td>
<td>5.8%</td>
</tr>
<tr>
<td>Amazonas</td>
<td>10,092,232</td>
<td>4,465,436</td>
<td>1,553,809</td>
<td>16,111,477</td>
<td>27.9%</td>
</tr>
<tr>
<td>Pará</td>
<td>9,343,004</td>
<td>9,275,134</td>
<td>4,922,076</td>
<td>23,540,214</td>
<td>40.8%</td>
</tr>
<tr>
<td>Rondônia</td>
<td>672,689</td>
<td>1,198,649</td>
<td>2,408,601</td>
<td>4,279,939</td>
<td>7.4%</td>
</tr>
<tr>
<td>Roraima</td>
<td>349,354</td>
<td>594,965</td>
<td>562,858</td>
<td>1,507,177</td>
<td>2.6%</td>
</tr>
<tr>
<td>Tocantins</td>
<td>2,931,330</td>
<td>2,026,316</td>
<td>953,881</td>
<td>5,911,527</td>
<td>10.2%</td>
</tr>
<tr>
<td>North Region - Total</td>
<td>27,176,948</td>
<td>19,293,712</td>
<td>11,207,468</td>
<td>57,678,127</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Figure 30. North Region: % GHG emissions per state (2009 – 2039)**
### Table 16. GHG emissions results per state – **Northeast Region** (2009 – 2039)

<table>
<thead>
<tr>
<th>States</th>
<th>Sanitary Landfill</th>
<th>Controlled Landfill</th>
<th>Dumpsite</th>
<th>Total Emissions (tCO₂e)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alagoas</td>
<td>636,530</td>
<td>6,573,187</td>
<td>2,833,867</td>
<td>10,043,584</td>
<td>6.4%</td>
</tr>
<tr>
<td>Bahia</td>
<td>21,978,789</td>
<td>10,860,729</td>
<td>5,462,262</td>
<td>38,301,779</td>
<td>24.5%</td>
</tr>
<tr>
<td>Ceará</td>
<td>18,737,619</td>
<td>11,168,751</td>
<td>4,136,103</td>
<td>34,042,474</td>
<td>21.8%</td>
</tr>
<tr>
<td>Maranhão</td>
<td>8,592,532</td>
<td>6,928,707</td>
<td>3,717,724</td>
<td>19,238,963</td>
<td>12.3%</td>
</tr>
<tr>
<td>Paraíba</td>
<td>6,685,373</td>
<td>3,600,195</td>
<td>1,382,224</td>
<td>11,667,793</td>
<td>7.5%</td>
</tr>
<tr>
<td>Pernambuco</td>
<td>13,733,299</td>
<td>6,130,162</td>
<td>3,022,002</td>
<td>22,885,464</td>
<td>14.6%</td>
</tr>
<tr>
<td>Piauí</td>
<td>3,787,076</td>
<td>1,489,593</td>
<td>717,618</td>
<td>5,994,288</td>
<td>3.8%</td>
</tr>
<tr>
<td>Rio Grande do Norte</td>
<td>3,028,603</td>
<td>3,351,777</td>
<td>1,176,446</td>
<td>7,556,825</td>
<td>4.8%</td>
</tr>
<tr>
<td>Sergipe</td>
<td>4,179,446</td>
<td>1,616,951</td>
<td>819,948</td>
<td>6,616,346</td>
<td>4.2%</td>
</tr>
<tr>
<td>Northeast Region – Total</td>
<td>81,359,268</td>
<td>51,720,052</td>
<td>23,268,194</td>
<td>156,347,515</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

### Figure 31. Northeast Region: % GHG emissions per state (2009 – 2039)
### Table 17. GHG emissions results per state – **Mid-West Region** (2009 – 2039)

<table>
<thead>
<tr>
<th>States</th>
<th>Sanitary Landfill (tCO₂e)</th>
<th>Controlled Landfill (tCO₂e)</th>
<th>Dumpsite (tCO₂e)</th>
<th>Total Emissions (tCO₂e)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distrito Federal</td>
<td>10,531,834</td>
<td>8,424,751</td>
<td>1,512,390</td>
<td>20,468,975</td>
<td>29.7%</td>
</tr>
<tr>
<td>Goiás</td>
<td>12,424,056</td>
<td>12,862,166</td>
<td>2,535,367</td>
<td>27,821,589</td>
<td>40.4%</td>
</tr>
<tr>
<td>Mato Grosso</td>
<td>5,173,252</td>
<td>4,210,635</td>
<td>1,941,901</td>
<td>11,325,788</td>
<td>16.4%</td>
</tr>
<tr>
<td>Mato Grosso do Sul</td>
<td>3,843,043</td>
<td>4,250,780</td>
<td>1,141,544</td>
<td>9,235,367</td>
<td>13.4%</td>
</tr>
<tr>
<td>Mid-West Region - Total</td>
<td>31,972,185</td>
<td>29,748,332</td>
<td>7,131,202</td>
<td>68,851,719</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Figure 32. Mid-West Region**: % GHG emissions per state (2009 – 2039)
### Table 18. GHG emissions results per state – Southeast Region (2009 – 2039)

<table>
<thead>
<tr>
<th>States</th>
<th>Sanitary Landfill</th>
<th>Controlled Landfill</th>
<th>Dumpsite</th>
<th>Total Emissions (tCO₂e)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Espírito Santo</td>
<td>16,419,661</td>
<td>2,591,775</td>
<td>797,291</td>
<td>19,808,727</td>
<td>3.7%</td>
</tr>
<tr>
<td>Minas Gerais</td>
<td>79,143,836</td>
<td>12,108,475</td>
<td>6,154,478</td>
<td>97,406,788</td>
<td>18.1%</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>105,013,271</td>
<td>18,061,218</td>
<td>4,754,272</td>
<td>127,828,760</td>
<td>23.8%</td>
</tr>
<tr>
<td>São Paulo</td>
<td>248,410,548</td>
<td>33,139,126</td>
<td>10,858,669</td>
<td>292,408,343</td>
<td>54.4%</td>
</tr>
<tr>
<td>Southeast Region – Total</td>
<td>448,987,315</td>
<td>65,900,593</td>
<td>22,564,710</td>
<td>537,452,618</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

### Figure 33. Southeast Region: % GHG emissions per state (2009 – 2039)
Table 19. GHG emissions results per state – **South Region** (2009 – 2039)

<table>
<thead>
<tr>
<th>States</th>
<th>Sanitary Landfill (tCO₂e)</th>
<th>Controlled Landfill (tCO₂e)</th>
<th>Dumpsite (tCO₂e)</th>
<th>Total Emissions (tCO₂e)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraná</td>
<td>24,858,873</td>
<td>3,439,524</td>
<td>978,105</td>
<td>29,276,502</td>
<td>40.7%</td>
</tr>
<tr>
<td>Rio Grande do Sul</td>
<td>23,476,216</td>
<td>2,975,212</td>
<td>1,129,933</td>
<td>27,581,362</td>
<td>38.4%</td>
</tr>
<tr>
<td>Santa Catarina</td>
<td>12,929,308</td>
<td>1,540,123</td>
<td>585,338</td>
<td>15,054,768</td>
<td>20.9%</td>
</tr>
<tr>
<td>South Region – Total</td>
<td>61,264,397</td>
<td>7,954,859</td>
<td>2,693,376</td>
<td>71,912,632</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Figure 34. South Region**: % GHG emissions per state (2009 – 2039)
In order to estimate the energy potential for the different final destination sites, the estimated volume of biogas that is generated must first be established.

After that, it is necessary to carry out a set of assumptions, which in this case are conservative so as not to overestimate the energy potential of biogas.

Different biogas-to-electricity providers have different specifications. The overall estimation is that about 670 – 800 m$^3$/h of biogas are necessary, with a 50% CH$_4$ concentration to ensure 1 MWe installed.

Additionally, not all biogas produced in different disposal sites can be collected. In fact, there will always be a fraction of it that ends up emitted to the atmosphere. Hence, by considering this calculation based on the capture efficiency experience at several final disposal sites and in order to provide simplification, about 40% of the biogas generated in each Brazilian region and state are considered as available for electricity production.

Some criteria must be also taken into account when estimating the potential. For example a very good understanding of how biogas generation behaves, the start and closing dates of disposal sites, and operating conditions of each site, among many factors.

Based on the previous results and the provided assumptions, the next table shows the biogas-to-electricity generation potential.
<table>
<thead>
<tr>
<th>Region</th>
<th>State</th>
<th>Total Emissions (m$^3$CH$_4$)</th>
<th>Emissions (m$^3$/h)</th>
<th>Potential (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>Paraná</td>
<td>1,944,920,684</td>
<td>7,401</td>
<td>9.3</td>
</tr>
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| Total      |                        |                               |                     | 103,509       | 282 |

Table 20. Biogas-to-electricity generation potential
Feasibility analysis on biogas utilization

7.1 Landfill Gas as a Source of Heat

7.1.1 LFG as Low-Grade Fuel

The use of LFG as a low-grade fuel requires a minimal level of gas processing. A condensate removal chamber as part of a LFG collection system reduces the amount of moisture in the gas stream. The LFG is then delivered ‘as is’ (raw landfill gas) to an on-site or off-site user. Low-grade fuel, following the removal of free moisture, is suitable for a variety of space and process heating applications, and as boiler fuel for production of steam for heating or electrical generation using steam turbines.

Low-grade LFG as heating fuel has the potential of being the most financially attractive of the utilization options. This results from the very low costs that are typically associated with this application and the energy conversion efficiency of direct use of LFG as a fuel, which is higher than for other utilization options. Where a high-volume, non-cyclical consumer of gas energy is located in proximity to a landfill, even a very small project can prove highly profitable.

Low-grade fuel, also described as raw LFG, may typically be utilized for fuelling a furnace, drying kiln or boiler. Low-grade LFG can be used at industrial facilities with low-to-medium-temperature process heat requirements or for space heating. Heating applications for LFG provide a more efficient conversion to energy than does generating electricity.

Due to the low heating value of raw LFG, the equipment used must be designed to operate on this fuel. The equipment must also be designed to withstand the various trace compounds in the LFG, which may be corrosive.

Ideally, the end-user of the LFG would have a consistent and adequate demand for the fuel and be in proximity to the landfill site, preferably within 10 km. The LFG is typically transported to the end-user through a dedicated pipeline. The primary factor in determining the marketability of low-grade LFG as a heating fuel is the
distance to the end-user and therefore the costs associated with transport of the fuel. District or city heating systems provide a stable basic heat demand that LFG rarely can oversaturate.

Raw LFG can be used for a range of applications, from heating a greenhouse to providing supplemental fuel for heating a major plant operation (i.e. a cement kiln, asphalt plant or chemical plant). Due to the wide range of potential end-users of LFG as a heating fuel, each candidate landfill site should be evaluated individually to determine marketability and economic feasibility.

Direct combustion of LFG is by far the cheapest and easiest reuse option. Direct use of LFG to replace or supplement coal, oil, propane, and natural gas has been successfully demonstrated. Applications include boiler firing, space heating, cement and brick kilns, sludge drying, and leachate drying and incineration. In most cases, gas cleanup consists of little more than condensate removal and equipment and procedural modifications are minimal. There is little risk for the end user in terms of gas quality, use, and continuity of supply. The payback period can be as little as a few months, but is extremely dependent on the negotiated price paid for the fuel replaced. The typical discounts of 10 to 20 percent are influenced by the pipeline distance and the gas quantity, quality, and variations permitted. The ideal situation is one where a user, located within a two-mile radius of the landfill, could accept all of the gas generated on a continuous basis.

### 7.1.2 Leachate Evaporation

Treatment of leachate is one of a number of environmental concerns when looking at the operation of a landfill. The design, construction and operation cost can be heavily influenced by the need of leachate treatment. Leachate can be treated in a normal wastewater treatment plant. In some cases the leachate is recirculated through the landfill, in which process some “self cleaning” of the leachate takes place. Another possibility is to use the landfill gas as fuel for evaporation of the leachate.

Many regulators have deemed LFG condensate a hazardous material, requiring treatment, and limiting direct disposal. Leachate, too, can reach toxic levels and in some areas is not allowed to be recirculated back into the landfill. Off-site disposal and treatment can incur transportation costs approaching US$ 1.00 per gallon. Transportation includes environmental and liability hazards of accidents, human error, and equipment failure causing spills and requiring sometimes extensive cleanup and remediation. Most wastewater treatment facilities prefer not to accept the condensate due to limited treatment capability and capacity. If accepted, actual responsibility for disposal has not been passed on to the treatment plant; liability may be traced back to the waste’s origin.

Up to 25 scfm (42 m³/h) of LFG is needed to treat one gallon of leachate, with a volume reduction of more than 97 percent. The exhaust vapors are combined with the LFG burner combustion gases with a resulting composition of predominantly water vapor with trace organics normally found in leachate and LFG. Fifty to sixty scf of LFG is burned at 1,600 °F (870 °C) in a modified enclosed flare (thermal oxidizer) to treat the gas/vapor mix
to greater than 95 percent VOC destruction. The sludge (concentrated leachate) produced passes USEPA TCLP (Toxicity Characteristic Leaching Procedure) tests, but metals and salts remain in the same proportions as the feed leachate.

7.1.3 Furnaces

LFG can be used directly or in combination with other fuel gases to fire up the furnaces of incinerators, kilns, industrial ovens, and brick ovens that do not require high-grade, high-quality fuel. To increase the heating value of the LFG, it is necessary to remove all non-combustible gases from it. This can be accomplished by water scrubbing, non-aqueous, solvent-based extraction systems, iron-oxide beds, activated carbon, pressure-swing absorption or membrane separation, or any combination of these techniques.

With this type of application, the LFG needs to be conveyed to the furnaces. Therefore, this application is limited to end-users in the vicinity of the landfill.

7.1.4 Steam Generation

LFG can be used to fuel boilers for the generation of steam. The steam generated can then be used for process heating, space heating, absorption chilling, and turbine shaft horsepower for driving generators and other shaft loads.

To increase the heating value of LFG, it is necessary to remove all non-combustible gases present in it. This can be accomplished by water scrubbing, non-aqueous, solvent-based extraction systems, iron-oxide beds, activated carbon, pressure-swing absorption or membrane separation, or any combination of these techniques.

In order to make the most use of this type of application, the LFG would need to be conveyed to the boiler room of the industrial site. Therefore, this application is limited to industrial sites in the vicinity of the landfill.

7.1.5 Space Heating

LFG can be used as a heating and/or drying source for commercial and industrial sites and greenhouses. In these applications, heating and/or drying can be accomplished by firing the LFG directly into the space or heating area, or indirectly through a heated medium like water or steam. Although direct firing provides a greater efficiency of heat transfer, directly firing LFG into a space can cause health and safety problems and may affect product quality. In order to increase the heating value of the LFG, and reduce these adverse effects, non-combustible gases present in the LFG can be removed. This can be accomplished by water scrubbing, non-aqueous, solvent-based extraction systems, iron-oxide beds, activated carbon, pressure-swing absorption or membrane separation, or any combination of these techniques. Depending on the type of application, this step might not be required.

Space heating for temperate climates can be uneconomical due to many factors. The heat energy supplied by a landfill producing 500,000 cubic feet (14,150 cubic meters) per day of LFG could serve the heating needs
of a very large building with the equivalent size of several square meters of floor space. Such buildings are few; fewer still are located near landfills. Piping costs become prohibitive beyond a two-mile (3 km) radius from the landfill. In climates with as little as two months of lows in the range of “winter” temperatures, the undesirable variation in load during the day and by season makes other options with more continuous fuel requirements appear more attractive. Absorption chilling can be combined with space heating to smooth load variation for LFG. Corrosion problems are relatively more frequent, making gas cleanup and equipment modifications more important. The equipment itself is economical and available for small scale.

7.1.6 Absorption Cooling and Heating Applications

One method of converting LFG, with limited application to date, involves absorption heating and cooling. As with space heating and drying applications, absorption cooling and heating can be accomplished by directly firing LFG into a space or heating area, or indirectly through a heated medium like water or steam. Indirect-fired systems utilize the thermal energy from an outside source, such as a boiler or an engine, thus eliminating the potentially corrosive nature of the LFG that acts on the absorption system itself. Indirect-fired absorption systems are less efficient that direct-fired systems, also direct-fired systems require considerable LFG clean up. This clean up can be accomplished by water scrubbing, non-aqueous, solvent-based extraction systems, iron-oxide beds, activated carbon, pressure-swing absorption or membrane separation, or any combination of these techniques.

7.1.7 Boiler

7.1.7.1 Introduction

The use of LFG in place of natural gas in boilers is an established and well-tested technology with a track record of over 20 years of success. A lot of companies have switched to the use of LFG in their commercial and industrial boilers. These companies recognize LFG as an attractive renewable fuel that offers significant cost savings — typically 10 to 40 percent net of conversion costs — in addition to environmental benefits. A facility manager that switches to LFG will also reap the benefits of a secure fuel supply at a constant and known price. Boilers and most process heating and co-firing applications are relatively insensitive to LFG combustion contaminants. Gas cleanup consists of condensate removal, sometimes by nothing more than condensate traps in the pipeline, and optional filtration. Corrosion problems with boilers have been reported, but may be alleviated by installation of stainless steel and other corrosion-resistant materials.

A common use of LFG takes place in gas furnaces, in which the gas is used for heating of water in a boiler system. This is a simple system, and reason for this solution not being the most used must be the fact that the price per kW power produced is almost higher than the price per kW heat. Another reason could also be that the power is relatively easily sold in unlimited quantities via the power distribution network.
7.1.7.2 Technology and Process Description

Facilities that use LFG in their boilers – “direct” end-users of LFG — can accommodate this new fuel through cost-effective retrofits to existing natural gas and oil-fired boilers, while maintaining their units’ efficiency. Boilers successfully retrofitted for LFG range in size from 2 million British Thermal Units per hour (MMBtu/hour) to 150 MMBtu/hour. The average boiler conversion can cost as little as several thousand dollars for minor adjustments on small boilers to tens of thousands for more elaborate retrofits on larger units.

To successfully retrofit a boiler for LFG use, certain characteristics of LFG must be taken into account. LFG has about half the heat content of natural gas (approximately 500 Btu) and burns at a lower temperature than natural gas due to the greater volume of nitrogen, carbon dioxide, and moisture contained in LFG. Minor modifications are needed to adapt a boiler to the greater gas flow, higher corrosivity, and lower flame temperature associated with LFG.

Since the methane content of LFG is half that contained in natural gas, the gas flow required to supply the same energy content with LFG is twice as great. To accommodate this difference in flow, the valve orifices for fuel control need to be enlarged. Using a larger fuel valve orifice can mean additional cost savings since this orifice reduces the amount of compression required to attain the boiler’s pressure specifications.

Corrosion potentially resulting from LFG use can be circumvented with technically simple solutions. Air pre-heaters and stacks are susceptible to corrosion from chlorine compounds in the exhaust gas of boilers that use LFG. Southfur trioxide (SO₃) formed from the sulfur content in LFG raises the dew point in boiler exhaust gas to approximately 280 degrees Fahrenheit (138° C). If the temperature of the exhaust gas falls below the dew point, the chlorine in the gas will corrode even stainless steel components.

Deposits of silica, iron, sulfur, and chlorine are known to accumulate on air pre-heaters and flue gas ductwork. The deposits are easily removed by soot blowing and manual cleaning during routine maintenance.

7.1.7.3 Application

The heat from some boiler systems is used in greenhouses, either by normal circulation of hot water, or by heating of air that is blown into the greenhouses. This is also a relatively simple and efficient way to use the gas.

7.1.8 Greenhouse Heating

Other landfill gas-to-energy projects have found LFG to be practical and cost effective to heat a greenhouse located near the landfill. While electricity is commonly used to power fans, lights, and other miscellaneous equipment, fuels such as oil, natural gas, and propane are typically burned to heat a greenhouse. Replacement of such fuels with LFG can result in significant savings in fuel costs. A greenhouse’s fuel needs depend on a number of factors:

- Crop type dictates the temperature that must be maintained. For example, carnations can tolerate temperatures in the low 50s, whereas roses require warmer temperatures.
Geographic location influences the amount of energy necessary to maintain the optimal growing temperature for a crop. At colder, northern latitudes, it takes between 100,000 and 200,000 Btu per square foot (ft²) of floor area per year to heat a greenhouse during the growing season.

The kind of building materials used to construct the greenhouse, from glazing materials to ventilation systems, affect energy demand. Glass, rigid plastic, or plastic film used for walls and ceilings each have different thermal efficiencies which allow different amounts of heat loss.

Note that the greenhouse would not need to be heated year-round and may only need to be heated for as little as 6 months per year.

### 7.2 Landfill Gas to Electricity

#### 7.2.1 Internal Combustion Engines

**Introduction**

The reciprocating internal combustion (IC) engine is the most commonly used conversion technology in landfill gas applications; the reason for such widespread use is their relatively low cost, high efficiency, and good size match with the gas output of many landfills. In the past, the general rule of thumb has been that IC engines have generally been used at sites where gas quantity is capable of producing 1 to 3 MW or where landfill gas flows are approximately 625,000 to 2 million cubic feet per day at 450 Btu per cubic foot.
IC engines are relatively efficient at converting landfill gas into electricity. IC engines running on landfill gas are capable of achieving efficiencies in the range of 25 to 35 percent. Historically, these engines have been about 5 to 15 percent less efficient when using landfill gas compared with natural gas operation, although the newest engine designs now sacrifice less than 5 percent efficiency when landfill gas is used. Efficiencies increase further in cogeneration applications where waste heat is recovered from the engine cooling system to make hot water, or from the engine exhaust to make low pressure steam.

IC engines adapted for landfill gas applications are available in a range of sizes, and can be added incrementally as landfill gas generation increases in a landfill. (The most commonly used IC engines for landfill gas applications are rated at about 800 and 3,000 kW).

Environmental permitting may be an issue for some IC engine projects. IC engines typically have higher rates of nitrogen oxide (NOₓ) emissions than other conversion technologies, so in some areas it may be difficult to obtain permits for a project using several IC engines. To address this problem, engine manufacturers are developing engines that produce less NOₓ using improved combustion and other air emission control features. These advances should give plant designers more flexibility to use IC engines on large projects.

7.2.1.2 Technology and Process Description

LFG projects typically use 4-stroke lean-burn engines that function similarly to automobile engines. These engines combust LFG with significant amounts of excess air to provide greater efficiency and lower NOₓ emissions. For power generation, the engine is connected to a crankshaft that turns an electrical generator to produce electricity.

7.2.1.3 Application

Engine models used at landfills range in size from approximately 0.5 to 3 MW, and are generally used in projects with capacities ranging from 0.8 to 6 MW (many with more than one engine). Recently, some smaller models have been developed.

Reciprocating engines are usually the most feasible and cost-effective electricity generation technology for landfills containing approximately 1 million to 5 million tons of waste, and have been used for landfills with up to about 10 million tons of waste. (An MSW landfill with 1 million tons of waste in place can typically support a 0.8 to 1 MW electricity project).

7.2.1.4 Advantages

The relative advantages of reciprocating engines include their low capital cost, reliability, less fuel processing requirements than turbines, and size-suitability to moderately sized landfills.

7.2.1.5 Disadvantages

Include higher NOₓ emissions and higher maintenance costs relative to other technologies.
7.2.1.6 Costs

The cost of LFG electricity generation projects using reciprocating engines is typically in the range of 4 to 7 cents per kilowatt hour (¢/kWh). These costs include capital, installation, and operating costs. Costs vary depending on whether an LFG collection system has already been installed and other site-specific technical factors, and how the project is financed (municipal versus private).

The installed capital costs for landfill gas energy recovery projects using IC engines are estimated to range from about $1,100 per net kW output to $1,300 per net kW. These costs are indicative of power projects at landfills ranging in size from 1 million metric tons to 10 million metric tons of waste in place, and the costs include the engine, auxiliary equipment, interconnections, gas compressor, construction, engineering, and soft costs. The costs associated with the landfill gas collection system are not included in these cost estimates.

7.2.2 Steam Turbine Generator System

7.2.2.1 Introduction

Boilers with Steam Turbines utilize the same systems as steam-electric power plants, and have been applied at only a few large landfills due to their capital intensive nature and size requirements.

7.2.2.2 Technology and Process Description

Water is heated to produce steam, which is expanded in a turbine to spin a generator, which produces electricity.

7.2.2.3 Application

They are suitable for MSW landfills containing 15 million tons of waste in place or more, and typically produce at least 10 MW of electricity.

7.2.2.4 Advantages

Boilers have high energy generation efficiencies and lower NOX emissions than reciprocating engines.

7.2.2.5 Disadvantages

Must be built in much larger sizes to be cost-effective, so are not suitable for the majority of LFG electricity projects.

7.2.2.6 Costs

For these large size projects, the costs range from approximately 4 to 7 ¢/kWh of electricity produced.
7.2.3 Gas Turbine Generator System

7.2.3.1 Introduction
Gas Turbines have been used at several large MSW landfills (generally for landfills with over 5 million tons of waste and projects that generate more than 5 MW of electricity).

7.2.3.2 Technology and Process Description
Gas turbines heat large quantities of compressed atmospheric air, which expands in the power turbine to develop shaft horsepower to drive an electrical generator.

Gas turbines are Brayton cycle engines which extract energy from hydrocarbon fuels through compression, combustion, and hot gas expansion. Air is drawn in to a compressor, which increases the air pressure. The compressed air is mixed with fuel and ignited in a combustor. Then, the hot gas is expanded through a turbine, which drives the compressor and gives useful work through rotation of the compressor – turbine shaft. The shaft power can be used to drive an electrical generator, thereby providing electricity.

Gas turbine operation is a relatively simple process. First, a pressure gradient draws air into a compressor stage in the turbine. An intercooler at this stage increases compressor efficiency by cooling the intake air, thereby increasing its density. The compressed air exits the compressor stage through an exhaust heat recuperator, which preheats the compressed air to increase combustion efficiency. The preheated compressed air is then mixed with fuel and combusted.

The resulting hot gas expands through the turbine, producing the mechanical energy required to generate electricity and operate the compressor stage of the turbine. Some turbines use a reheat combustor to

Figure 35. Gas turbine operation
maximize the combustion and expansion of the gas through the turbine. The hot exhaust gas is then passed through the heat recuperator to preheat the incoming compressed air. The resulting hot gas expands through the turbine, producing the mechanical energy required to generate electricity and operate the compressor stage of the turbine. Some turbines use a reheat combustor to maximize the combustion and expansion of the gas through the turbine. The hot exhaust gas is then passed through the heat recuperator to preheat the incoming compressed air.

7.2.3.3 Application

The relatively high capital cost of turbines, higher fuel pressure requirements and lower power generation efficiency tends to render them less suited for small or moderately sized landfills, which represent the majority of the remaining potential LFG electricity projects.

7.2.3.4 Advantages

Gas turbines use large amounts of excess air and the gas/air mixture has a relatively short residence time in the combustion zone. These factors result in rapid cooling of the combustion reaction to temperatures that are not conducive to NOx formation, leading to lower NOx emissions than reciprocating engines. Another general advantage of turbines is their relatively low maintenance costs.

7.2.3.5 Disadvantages

A disadvantage for use in typical LFG electricity projects is that turbine models currently available for landfills tend to be larger than 3 MW.

7.2.3.6 Costs

The costs to generate electricity using turbines are typically about 10%, higher than reciprocating engine costs for landfills containing up to 5 million tons of waste. Turbines can become more economical for large landfills (those approaching 10 million tons of waste), with costs ranging from approximately 4 to 7 ¢/kWh for such landfills. Costs vary depending on whether an LFG collection system is already in place and other site-specific technical factors, and how the project is financed (municipal versus private).

7.2.4 Microturbines

7.2.4.1 Introduction

Microturbines are a commercialized technology that has been demonstrated at several MSW landfills, with the first LFG-fired units coming on line in 2001.
Microturbines are an emerging LFG energy recovery technology option, especially at smaller landfills where larger electric generation plants are not generally feasible due to economic factors and lower amounts of LFG. Several LFG microturbine projects have come on line, demonstrating both the risks and benefits of these small-scale applications. Microturbines may play an important role in future LFG project development, if the technical and economic hurdles facing them can be overcome.

Microturbines are generally best suited to relatively small applications (i.e., less than 1 megawatt [MW]) and are designed to produce electricity for onsite energy needs and for end users in close proximity to the generation site. As a point of reference, the output of a 30-kilowatt (kW) microturbine can power a 40 horsepower (HP) motor or satisfy the electricity needs of about 20 homes.

To date, most microturbines on the market are powered using natural gas. However, they can also be operated using LFG or other waste fuels, such as oilfield flare gas and wastewater treatment plant digester gas.

7.2.4.2 Technology and Process Description

They are based on the same design principles as much larger gas turbines, but generate much smaller amounts of electricity. For example, typical microturbine models generate 30 to 100 kW of electricity.

Microturbine technology is based on the design of much larger combustion turbines employed in the electric power and aviation industries. Microturbines generally work as follows:

- Fuel is supplied to the combustor section of the microturbine under 70 to 80 pounds per square inch gauge (psig) of pressure.
- Air and fuel are burned in the combustor, releasing heat that causes the combustion gas to expand.
- The expanding gas powers the gas turbine that in turn operates the generator; the generator then produces electricity.
- To increase overall efficiency, microturbines are typically equipped with a recuperator that preheats the combustion air using turbine exhaust gas. A microturbine can also be fitted with a waste heat recovery unit to heat water.

A general schematic of the microturbine process as well as a cross-section of one microturbine that is currently available for LFG application (lower illustration) is shown to illustrate how a microturbine operates (Figure 36).

Microturbines differ from traditional combustion turbines in that they spin at much faster speeds. Those currently on the market are equipped with air bearings rather than traditional mechanical bearings in order to reduce wear. A typical LFG-fired microturbine installation has the following components:

- LFG compressor(s);
- LFG pretreatment equipment (for moisture, siloxanes and particulates removal);
- Microturbine(s);
- Motor control center;
- Switchgear;
- Step-up transformer.
The extent of fuel pretreatment steps required depends on the characteristics of the LFG and varies by microturbine manufacturer. In some instances, the gas is chilled to remove moisture and condensable impurities and is then reheated to supply fuel above dew point temperature to the microturbine. In addition to moisture removal, some manufacturers recommend an adsorption step using activated carbon to remove virtually all impurities.

7.2.4.3 Application

Their size makes them generally best suited for relatively small applications, typically 1 MW or less. Microturbines provide unique advantages over other electrical generation technologies for landfills in cases where:

- LFG flow is low (or excess flow from an existing project is available).
- LFG has low methane content.
- Air emissions, especially nitrogen oxide (NOx), are of concern (e.g., in NOx non attainment areas where the use of reciprocating engines might be precluded).
- Electricity produced will be used for onsite facilities rather than for exporting power.
- Electricity supply is unreliable and electricity prices are high.
- Hot water is needed on site or nearby.

7.2.4.4 Advantages

Advantages of microturbines include lower NOx emissions, portability, and low maintenance requirements relative to reciprocating engines.

LFG microturbines offer the following advantages when compared to other types of LFG utilization technologies:

- Portable and easily sized. Microturbines are modular and available in incremental capacities for multiple-unit stacks, so that single or multiple microturbines can be configured to adapt to gas flow and satisfy onsite power requirements. They can then be moved to another project site when gas production ceases.
- Flexibility. Microturbines may be a more viable option at smaller and older landfills where LFG quality and quantity would not support more traditional LFG electric power generation technologies. They may also be feasible at larger LFG projects that have excess unutilized gas.
- Compact and fewer moving parts. Microturbines are approximately the size of a large refrigerator and require minimal operation and maintenance. The use of air bearings coupled with an air-cooled generator eliminates the need for lubrication and liquid cooling systems.
- Lower pollutant emissions. Microturbines burn cleaner than comparable reciprocating engines. For example, NOx emissions levels from microturbines are typically less than one-tenth those of the best performing reciprocating engines and lower than those from a LFG flare.
• Capable of combusting lower-methane-content LFG. Microturbines can operate on LFG with 35 percent methane content and perhaps as low as 30 percent.

Ability to generate heat and hot water. Most microturbine manufacturers offer a hot water generator as a standard option to produce hot water (up to 200°F) from waste heat in the exhaust. This option can replace relatively
expensive fuel, such as propane, needed to heat water in colder climates to meet space-heating requirements. The sale or use of microturbine waste heat can significantly enhance project economics.

7.2.4.5 Disadvantages

Disadvantages include high capital costs, high fuel pressure requirements, gas treatment requirements, and relatively low energy conversion efficiency.

Disadvantages of microturbines as a LFG utilization option include:

- Microturbines have a lower efficiency than reciprocating engines and other types of turbines, and they consume about 35 percent more fuel per kWh produced.
- Microturbines are sensitive to siloxane contamination, and LFG supplied to microturbines is generally expected to require more pretreatment than LFG used to power conventional turbines or other electric generation sources.
- Currently, few low-flow, high-pressure compressors are available that meet the needs of microturbines without high equipment modification costs; a suitable solution would need to be identified to permit cost-effective delivery of LFG to microturbines without significantly increasing the parasitic load.
- Information needs to be gathered about the long-term reliability and operation and maintenance costs of LFG microturbines.

7.2.4.6 Providers

Bowman Power (Southampton, England); Capstone Turbine Company (Chatsworth, California); Elliott Energy Systems (Jennette, Pennsylvania); Ingersoll-Rand (Portsmouth, New Hampshire); and Turbec (Malmo, Sweden).

7.2.4.7 Costs

For Brazil, the estimated costs for LFG microturbine electricity generation projects are generally 7 to 14 ¢/kWh. The lower end of the range would represent a landfill that has a gas collection system already in place (which is unlikely for small landfills) and generates power for on-site use, avoiding costs associated with connection to the power grid.

Microturbine heat rates are generally 14,000 to 16,000 Btu/kWh. The total installed cost for a LFG microturbine project is estimated to be $ 4,000 to $ 5,000 per kW for smaller systems (30 kW), decreasing to $ 2,000 to $ 2,500 per kW for larger systems (200 kW and above). Non-fuel operation and maintenance costs are about 1.5 to 2 ¢/kWh.

LFG microturbine projects are most economical under a retail deferral scenario. (Retail deferral is the replacement of purchased electric power by self-generated power.) In many cases, the cost to generate electricity with microturbines will be higher than the price for which it can be sold to utilities.
7.3 Landfill Gas to Natural Gas\(^{22}\)

LFG typically contains about 40 to 55 percent methane when it reaches the landfill’s flare station, with the balance of the gas consisting primarily of carbon dioxide and secondarily of air (nitrogen plus oxygen) plus water vapor. LFG also contains trace compounds including NMOCs (such as toluene, trichloroethylene and vinyl chloride) and hydrogen sulfide. LFG has a heating value (HHV) of about 14.9 to 20.5 MJ/m\(^3\) (400 to 550 Btu/ft\(^3\)). LFG can be used to displace natural gas use in two ways. First, it can be subjected to light cleanup and be transmitted to an end user through a dedicated pipeline. The product gas retains its original energy content and the LFG displaces or is blended with natural gas at its point of use. Natural gas has a heating value of about 37.3 MJ/m\(^3\) –1,000 Btu/ft\(^3\)– (HHV). As discussed above, this “direct use” of LFG is commonly known as “medium-Btu” gas use.

A second way to displace natural gas is to inject it into an existing natural gas distribution network. Natural gas, as distributed through pipelines to customers, must meet strict quality standards. Pipeline operators will allow LFG to enter their pipelines only after the LFG has been processed to increase its energy content and to meet strict standards for hydrogen sulfide, moisture, carbon dioxide and NMOCs. The need to roughly double the energy content of LFG has lead the LFG utilization industry to call gas beneficiated to pipeline quality “high-Btu” gas.

A typical pipeline quality gas specification is as follows:

- Heating value (HHV) \(> 36.1\) MJ/m\(^3\) (970 BTU/ft\(^3\))
- Hydrogen Sulfide < 4 ppmv
- Water Vapor < 0.11 g/m\(^3\) (7 lbs/million ft\(^3\))
- Oxygen < 0.4 %
- Carbon Dioxide < 3 %
- Nitrogen plus Carbon Dioxide < 5 %

The 36.1 MJ/m\(^3\) – 970 Btu/ft\(^3\)– (HHV) limitation requires, in effect, that oxygen plus carbon dioxide plus nitrogen be limited to less than 3 percent. The product gas must also be free of environmentally unacceptable substances and must be pressurized to the pressure of the pipeline to which the gas production facility is interconnected. Pipeline pressure typically varies from 100 to 500 psig.

The following steps must be taken to convert LFG to pipeline quality gas:

- Prevention of air infiltration into the LFG well field;
- Moisture removal;
- Sulfur removal;
- NMOC removal; and
- Carbon dioxide removal.

If the gas is meant for input in a natural gas piping system, the gas has to be cooled and has to be compressed. Dust and halogenated hydrocarbons have to be removed, and the gas needs to be odorized for safety reasons.

\(^{22}\) This section is an excerpt of “Emerging Landfill Gas Utilization Alternatives: Pipeline Quality Gas; Vehicle Fuel; Hydrogen; Methanol and Fuel Cells”, SCS Engineers, Jeffrey L. Pierce, February 1999.
The removal of carbon dioxide is the principal step taken to increase energy content. The prevention of air infiltration into the well field is also a critical step, not only because air infiltration reduces energy content, but also because it is necessary to satisfy tight product gas nitrogen and oxygen limitations. The addition of processing steps to remove nitrogen and oxygen from the LFG is widely viewed as being prohibitively expensive. At most landfills, elimination of air infiltration will require that the utilization facility be supplied by wells located in the “core” of the landfill. A separate perimeter LFG collection system must often be operated for gas migration control. Each well on the core gas system must be carefully monitored to maintain as close as practical “zero” air infiltration operation.
Potential programs or public subsidies that stimulate renewable energy production

One important milestone for renewable energy generation incentive programs in Brazil occurred in 2004, when Law 10,438/02 and Decree 4,541, respectively, created and regulated the Brazilian Alternative Energy Source Incentive Program (in Portuguese, PROINFA). The PROINFA had the following purposes: diversification of the Brazilian energy matrix, increase of safety in power supply, and valorization of the characteristics and energy potentials in each region of the country. One of the PROINFA’s consequences was the reduction of greenhouse gas emissions and a significative number of CDM projects being developed.

Brazil’s National Plan on Climate Change was created in 2007 to identify, plan and coordinate actions aimed at mitigating GHG emissions, and adapting the community for impacts resulted from climate change. In 2010, after the approval of the National Policy on Climate Change, the National Fund on Climate Change (Climate Fund) was created to provide financial support to projects and studies focused on adaptation and mitigation of climate change. Within this context, the Brazilian Economical and Social Development Bank (BNDES) also gave the possibility of funding renewable energy projects.
8.1 Brazilian Alternative Energy Source Incentive Program – PROINFA

The PROINFA’s aim was to increase participation of electricity produced by Autonomous Independent Producers (in Portuguese, PIA) using wind power plants, small hydro power plants (SHP), and biomass power plants, within the Brazilian Interconnected System (SIN).

PROINFA’s first stage considered that contracts should be dealt with by Centrais Elétricas Brasileiras S.A. - ELETROBRÁS, with the expected installation of 3,300 MW in additional capacity to the Brazilian electrical system from renewable sources, with 1,100 MW for each type of source: wind, small hydro, and biomass power plants (biomass generation included electricity generated from biogas, wood, sugarcane bagasse, and rice husk). The program would buy the energy produced during 20 years, assuring to entrepreneurs the minimum revenue of 70 percent of the contracted power.

The PROINFA also provided that in case of failure to meet the targets set for each of the sources, ELETROBRÁS would immediately contract the remaining power quotas among projects enabled for other sources, according to the Antiquity Criterion of the Installation Environmental Permit.

The PROINFA also required that, in order to participate in public bids, power producers must prove that a minimum percentage of their equipment and services are of national origin – sixty percent (60%) for each enterprise during the program’s first stage, and ninety percent (90%) in the second stage. Hiring of the facilities would occur via Public Bid, taking into account the following criteria:

- Facilities that already have an Installation Environmental Permit (LI);
- Facilities that already have a Prior Environmental Permit – LP.

The PROINFA’s second stage considered that, once the initial implementation target of 3,300 MW has been met, the Program would develop based on wind, small hydro and biomass power plants generating 10% of the annual electricity consumption in the country up to 20 years, thus incorporating the term and results of the first stage.

The PROINFA received financial support from the following institutions:
- Brazil’s National Economical and Social Development Bank (BNDES);
- Banco do Brasil (BB);
- Banco da Amazônia S.A (BASA) and Amazon Development Agency (ADA – Amazon Development Fund).

The Table 22 shows that the prices that were established for electricity generated from the different sources were aimed at boosting the development of the different energy alternatives. In some cases, such as wind power, these values continue to be higher than those paid in the recent energy auctions.

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23 Should there be more facilities with LI/LP than the hiring availability from Eletrobrás, it was agreed that priority should be given to those facilities whose environmental permits have shorter remaining validity periods.
The PROINFA energy hiring process resulted in an amount of approx. 12.6 million MWh/year, with an approximate cost of R$ 1.82 billion/year, as per the following Table 23.

Overall, 144 projects were hired, with a contracted total of 3,299.40 MW, as follows:

- SHP: 63 projects = 1,191.24 MW
- Wind: 54 projects = 1,422.92 MW
- Biomass: 27 projects = 685.24 MW

Given the low values set for biomass, as well as barriers of the program (such as minimum rate of nationally-produced equipment, and a prior environmental permit), the expected hiring of biomass power turned out to be unfeasible. The situation was not different for biogas-to-energy projects and, thus, no project was hired at all.

<table>
<thead>
<tr>
<th>Source</th>
<th>Pot. Hired (MW)</th>
<th>Energy (MW/h/year)</th>
<th>Cost (MR$/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHP</td>
<td>1,191.24</td>
<td>6,511,196</td>
<td>800</td>
</tr>
<tr>
<td>Wind</td>
<td>1,422.92</td>
<td>3,719,799</td>
<td>786</td>
</tr>
<tr>
<td>Biomass</td>
<td>685.24</td>
<td>2,304,992</td>
<td>233</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,299.40</strong></td>
<td><strong>12,555,987</strong></td>
<td><strong>1,819</strong></td>
</tr>
</tbody>
</table>

Table 22. PROINFA economic values
Source: ELETROSUL PROINFA, 2006

Table 23. Energy Hiring Process
Source: ELETROSUL PROINFA
The value paid did not assure return on investment and, according to experts, biogas-to-energy generation was made feasible only after the sale of carbon credits (GUSMÃO 2003\textsuperscript{24} \textit{apud} GAZETA MERCANTIL 2003).

Thus, a second auction was held in order to hire the remaining electricity from biomass. However, in this auction, the most benefited source was wind power, with a higher price than that offered for biomass.

### 8.2 Reduction of fees by the Brazilian Electric Energy Agency – ANEEL

After that, the Brazilian Electric Energy Agency – ANEEL revised the fees for the use of transmission/distribution electric systems, eliminating fees that were applied to certain sources until then.

After the results of Public Hearing 011/2004 that aimed at obtaining subsidies and setting up procedures to reduce fees for the use of energy transmission/distribution systems, ANEEL revised the fees of Normative Resolution 77 of August 18, 2004. This revision assured the right of a 100-percent reduction in the fees for the use of energy transmission/distribution systems, with impact on production and consumption of the power sold by hydro projects with capacity equal or lower than 1,000 kW (called Small Hydro Power Plants), and those based on sun, wind, biomass or cogeneration, with power injected to transmission/distribution systems lower than or equal to 30,000 kW. For the exemption of fees for biomass, the energy input for production must also include at least 50% biomass from Municipal Solid Waste and/or Landfill Gas, or biodigesters for animal/vegetal waste, as well as sludge from sewage treatment plants.

This decision led to a significant improvement of landfill gas utilization, and the installation of GHG mitigation and biogas-to-energy projects became more feasible.

### 8.3 National Fund on Climate Change (Climate Fund)

The Climate Fund was created in 2010 as an instrument of the Brazilian Policy on Climate Change set up by the Ministry of Environment (MMA) to obtain resources to support projects aimed at mitigation of and adaptation to climate change.

These projects are funded by resources derived from a special participation in profits from the oil production chain. The amount first budgeted was R$ 226 million, as follows:

- R$ 200 million for loans and funding of the production sector by BNDES\textsuperscript{25}. For waste projects with energy utilization and renewable energy, BNDES sets a one-percent decrease in the interest rate over usual rates.
- R$ 26 million administered by the MMA for investment in research projects, mobilization and climate change impact assessment. Amounts from this share might be provided to states and municipalities through agreements and cooperation terms.

\textsuperscript{24} Gusmão M.V., Crédito de Carbono Impulsiona usinas (Carbon Credit Boosts Plants), Gazeta Mercantil
\textsuperscript{25} Money transferred from MMA to BNDES.
The fund may also receive resources from other sources, including international donations, that might arise within the scope of the United Nations Framework Convention on Climate Change (UNFCCC). It has six sub-programs, with special focus on two specific ones:

- Renewable Energy; and
- Waste for Energy Utilization.

### 8.3.1 Climate Fund – Renewable Energy

This sub-program supports investments for the implementation of energy generation projects in isolated systems that, in their natural setting, are not connected to the Brazilian Interconnected System – SIN. These include projects involving wind power capture, solar radiation-to-energy, tidal and wave power, and biomass (except sugarcane). The sub-program also aims at establishing projects for technological development or development of the production chain for wind, tidal and wave, or sun power, including silicon purification plants.

### 8.3.2 Climate Fund – Waste for Energy Utilization

This sub-program supports projects aimed at rationalization of urban sanitation and waste disposal in order to use waste to produce energy in one of the cities that will host the 2014 FIFA World Cup, or in its respective metropolitan area.

Support to the ventures is based on deploying urban sanitation rationalization projects associated with energy utilization from waste disposal, and on deploying, modernizing and extending projects intended for energy utilization from waste disposal.

### 8.4 National Plan on Climate Change – PNMC

Created in 2008, Brazil’s National Plan on Climate Change is administered by the Ministry of Environment to provide guidance, structure and coordination to actions of the government and other sections of the society (manufacturing, waste, financial, agriculture and forestry, among others) to reduce greenhouse gas emissions.

Its targets are: to identify, plan and coordinate actions to mitigate emissions and prepare the society for impacts from climate change, foster performance efficiency in the multiple economical sectors, keep a high share of renewable energy sources in the Brazilian energy matrix, promote sustainable increase of the biofuels’ share in the Brazilian transport matrix, seek for a sustained decrease in illegal deforestation until reaching zero deforestation, eliminate the net loss of forest area in Brazil by 2015, enhance actions between sectors in order to diminish vulnerabilities of populations, identify environmental impacts from climate change, and support scientific research.
According to the CEPEA/ESALQ studied requested by the Ministry of Environment in 2005, Municipal Solid Waste represents 12% of the total methane emission sources in Brazil, 84% of which comes from landfills (PNMC, 2008). Thus, the plan included mitigation actions for waste by recovering CH₄ in sanitary landfills, incineration with energy recovery, and recycling, as well as setting incentive targets for the use of landfill gas to energy.

According to the PNMC, the federal public sector funds the final disposal and infrastructure system for the Waste sector. This funding comes from voluntary transfers[^26] from the Ministry of Cities, Ministry of Health (FUNASA), and Ministry of Integration (CODEVASF).

[^26]: Voluntary transfers are the delivery of current or capital resources to another entity in the Brazilian Federation with the purpose of cooperation, help or financial assistance, not resulting from constitutional or legal ordinance, or intended for Brazil's Unified Healthcare System (Complimentary Law 101/2000, art. 25). Available at: [http://www.senado.gov.br/sf/senado/ib/pdf/ManualObtRecFedMun20052006/Cap_02.pdf](http://www.senado.gov.br/sf/senado/ib/pdf/ManualObtRecFedMun20052006/Cap_02.pdf)
9 Conclusions and recommendations

As evidenced in the country’s latest Greenhouse Gas Emissions Inventory, the MSW disposal sector is one of the main contributors of GHG emissions in Brazil.

According to recent sectoral statistics of the last years, there was an increase in sanitation service coverage, as well as in the percentages of collection and destination of waste in sanitary landfills. However, much remains to be done, as much of the waste in Brazil is not collected, and another part is not disposed of appropriately, all of which has a significant environmental impact.

Waste generation is also expected to continue growing, reflecting both population and economic growth.

The Southeast and Northeast Regions are expected to account for approximately 75% of waste generation in the country in the coming years. Likewise, these regions will be responsible for a similar percentage of all GHG emissions generated.

However, it should be noted that the Southeast Region, although the main GHG emitter in the country, is also the region with the highest percentage of sanitary landfill disposal (72%). It also has mitigation projects implemented and with implementation potential. Thus, mitigation efforts should be directed to those regions where the sanitary landfilling share is still low, and to regions with a significant occurrence of controlled landfills and dumpsites, such as North, Northeast, and Mid-West.

The South Region is similar to the Southeast, in that it also has a major participation of final waste disposal in sanitary landfills (70%).

In order to minimize the impact of emissions from solid waste disposal sites, conditions must be created to encourage the development of mitigation projects.

The CDM fostered in an effective way the development of mitigation and emission mitigation projects in the Brazilian sanitary landfills.

Prior to the CDM, few waste disposal sites implemented proper gas management practices. However, the overall results of the CDM can only be described as fair, since despite the occurrence of an important amount of projects (46) and the
estimated mitigation potential of about 12 million tCO₂e/year, nearing the end of the Kyoto Protocol's first commitment period, only 9.1 million CERs were effectively issued in Brazil.

Nevertheless, this does not mean that mitigation under Kyoto is limited to this amount. On the contrary, many initiatives are effectively taking place, but some inherent inefficiencies of the CDM system have prevented project owners from recovering their investments, and there are no public records of the monitoring reports, although mitigation is actually taking place.

The CDM also led to some negative aspects in some projects. Thus, many projects originally intended for biogas capture and flaring identified an opportunity for utilizing this energy resource. However, contractual agreements with CER purchasers and the stringency and lack of flexibility of the system, among other things, halted a more significant use of the energy potential.

Knowledge brought to the sector by the CDM helped to understand some details of biogas generation inside landfills, which helped many companies make decisions about the implementation of mitigation projects.

In order to complement the benefits that CDM has brought to the sector, further stimuli should be created either through subsidies or through some other scheme in order to boost implementation of mitigation projects, as well as energy utilization of biogas. Current incentives have had no significative impact, and the decision of implementing a project depends on the specific conditions of each project. However, extreme care must be taken when developing new incentives to avoid affecting the natural conditions of the energy market.

The creation of a biogas atlas in Brazil has made it possible for the first time to compile information to integrate national statistics on generation, collection, and final destination with information on emissions, mitigation, technologies, and energy potential for biogas.

This information will be very useful to carry out an analysis of the results achieved to date, project GHG emissions, and track sector developments. Updating this information will provide all interested stakeholders with first-hand information.
Bibliography


Promotion of practical GHG emissions reduction through the Bilateral Offset Mechanism including REDD+Projects. METI. December 2010.


CASE STUDY

The full case study is available in the digital edition of this document, which can be obtained online through the website www.abrelpe.org.br.
Case Study: CTR São Mateus

The São Mateus Sanitary Landfill is a new, not yet operational project. It is expected to begin operating in 2014. It is located in the Nestor Gomes district, city of São Mateus, in Espírito Santo state, and can be accessed through highway ES-381, km 41.

The landfill will partly supply the Regional Proper Urban Waste Disposal System of the “Espírito Santo Sem Dumpsite” (“Garbage-less Espírito Santo”) project, more specifically, the final disposal site in the north region, comprised by the municipalities of Água Doce do Norte; Barra de São Francisco; Boa Esperança; Conceição da Barra; Ecoporanga; Jaguaré; Montanha; Mucurici; Nova Venécia; Pedro Canário; Pinheiros; Ponto Belo; São Mateus; Sooretama and Vila Pavão.

According to the information provided, the landfill is expected to meet the needs of a population of about 397,000 inhabitants and receive about 362 tons of waste/day as of its first operational year.

A biogas recovery project is expected to develop different ways of utilization according to the final intended use of the biogas. Among these:

- Flaring of Landfill gas (LFG) for combustion;
- Purification of biogas for sale as a high-heat power fuel;
- Electricity production;
- LFG as a heat source (LFG as a low-heat power fuel for leachate evaporator, boilers, etc).

The best alternative for this project seems to be the capture and flaring of biogas to generate electricity over several stages. This is basically due to the amount of biogas that might be available, the investment required for the different alternatives, the lack of final users to directly use the LFG, and the absence of industrial facilities in the vicinity of the landfill, as well as previous experiences with other projects in Brazil.

The conceptual design of the biogas capture and utilization system for this landfill includes a set of gas wells and a system to destroy and use the biogas. Basically, this conceptual design includes a well field comprised of vertical wells,
and possibly some horizontal ones, connected through pipelines from the well field to the flaring station. The flaring station includes an enclosed flare, blowers to push biogas from the landfill, and an electrical power plant comprised by an engine, a generator and ancillary equipment powered by landfill gas. The power plant's capacity is estimated to be 1.0 MW.

When landfill gas is used to produce electricity, installing a flare for its combustion is not necessary. However, due to the conditions of this project, during its first years biogas should be flared until reaching a recovery amount that justifies installing an electrical plant.

The initial investment for a LFG recovery-and-use project in the São Mateus Landfill is of about US$ 2.0 million, which includes US$ 269,000 for the capture network, US$ 450,000 for the flare station, and US$ 1.2 million for the electrical power plant. This cost estimation covers the main equipment, interconnection of the electric network and other professional services, and the cost of purchase, delivery and installation of the equipment.

The estimated destruction of methane with a 90-percent efficiency rate might result in about 11,362 tCO₂e/year of GHG reduction as of the first operating year. The annual emission reduction would increase to about 42,748 tCO₂e in the twenty-fourth operating year, given that the greater the amount of waste that is disposed in the landfill, the higher the annual methane generation is.

If biogas is flared in engines, the combustion efficiency becomes 100%, and the emission of 0.3 tons of carbon dioxide per MWh produced will be avoided by fuel switching from fossil fuel to produce electricity. Considering that LFG not used in engines will have a 90-percent flare efficiency, the accumulated emission reductions estimated until the twenty-fourth year will be of about 795,175 tCO₂e. The generated power recommended from the landfill gas-to-energy project is 1.0 MW, even if we consider that biogas generation will reach its maximum in the twenty-first operating year.

To ensure proper performance in the flaring and utilization of landfill gas, the project should ideally be integrated to the engineering and construction schemes in the landfill from the very start. In addition, the higher the synergy between the landfill operator and the company in charge of the biogas utilization project, the greater will be the chances of success of the project. In many cases, these kind of projects fail because there is no proper articulation between the involved parties. This is a very interesting aspect for the São Mateus case, as the project is at the first stage of development.
Case Study: CTR Santa Rosa

The project for landfill gas recovery and use in this landfill is included in a CDM-based Program of Activities (PoA) in Brazil called CDM PoA: Projeto de Gerenciamento de Resíduos Sólidos e de Carbon Finance da Caixa Econômica Federal. This PoA was registered with the UNFCCC on October 5, 2012.

The privately-operated CTR Santa Rosa landfill is located in the Rio de Janeiro state, in the municipality of Seropédica, near the city of Rio de Janeiro, Brazil’s second most populated city. CTR Santa Rosa occupies an area of 1,699,512 m², and began receiving waste in March 2011, after obtaining all required environmental permits. The project’s first estimation was that it would receive a daily amount of 6,000 tons of domestic solid waste during the first year, from the municipalities of Rio de Janeiro, Seropédica, and Itaguaí.

CTR Santa Rosa’s landfill gas project aims to capture/utilize methane from organic waste decomposition. The project intends to generate electricity from methane combustion, and distribute LFG through the natural gas pipeline when the flow of LFG is sufficient.

The project is summarized as follows:

- Implementation of a LFG capture system at the site;
- Use of captured biogas as fuel to produce electricity, which could be used on-site or sold to the Brazilian Interconnected System (SIN);
- Use of captured biogas for distribution to consumers through the natural gas network; and
- Flaring of the excess captured LFG to destroy any methane emissions.

Based on the assumptions and input values for the biogas estimation model for CTR Santa Rosa landfill, biogas generation for 2013 could reach 16,424 m³/hour. By 2032, after 21 years of operation, this generation rate should reach 45,775 m³/hour.

For the CDM project, the estimated capture efficiency of the generated biogas is around 50 percent, which shall remain constant over the project’s lifetime. This assumption is reasonable and conservative, as during the landfill’s operation, the waste mass will contain exposed areas for the biogas to migrate through.

Assuming a 50 percent collection efficiency, the estimated amount of biogas to be captured in 2013 is 8,212 m³/h, which equals 4,106 m³/h of methane (CH₄), considering a 50-percent CH₄ composition in biogas.

With regards to generation capacity, the estimated maximum capacity is 25.47 MW. Electricity generation engines will be installed on a progressive basis, in three-unit packages each one.
The total investment required to implement the project could exceed US$ 44,000,000, the larger portion of which would correspond to the landfill gas process plant (US$ 22,295,562) and the landfill gas collection system (Perforation + Pipes + Vertical wells + Leachate pumps + Welding/Assembly).

The project is very interesting because it includes three components associated with final destination for the recovered biogas. The estimated emission reductions would be of 6 million tCO$_2$e during the first 7 years of the project (2012-2019). The project is expected to reduce 509,744 tCO$_2$e in 2013 and reach about 1,075,013 tCO$_2$e in 2019. The average annual emission reductions are estimated to be 794,672 tCO$_2$e.

Besides resulting in GHG emission reduction, the project involves other aspects and additional benefits that contribute towards sustainable development. Implementing this kind of project entails operating the landfill under strict controls, which could prevent the occurrence of other environmental impacts. In addition, a large workforce will be required during the construction and operation stages, there will be significant technology transfer and capacity-building in biogas management topics, and the project will be highly innovative in its approach to using a nonconventional, renewable energy source to replaces fossil fuels.
Case Study: CTR Candeias

The CTR Candeias landfill began operating in August 2007 after receiving all environmental permits for its operation. The landfill was designed to operate for a 16-year period, and therefore will be closed in late-2022. This municipal landfill occupies an area of over 170,000 m², and will receive about 11 million tons of solid waste over its 2007-2022 life period.

CTR Candeias landfill gas project aims at capturing and flaring methane (CH₄) produced during decomposition of organic waste disposed of in the landfill. The project is located in the municipality of Jaboatão dos Guararapes in the metropolitan area of Recife, capital city of Pernambuco state. It also intends to produce electricity from methane combustion and sell it to the Brazilian Interconnected System (SIN), thus reducing CO₂ through displacement of electricity that otherwise would be produced from burning fossil fuels in the Brazilian energy matrix.

The project consists of a LFG capture system, a LFG pretreatment system, an enclosed flaring system, an electricity generation system, and an interconnection system to the SIN. At first, it is captured, and then it passes through a pipeline to the pretreatment system, where moisture is removed. The LFG then goes to the enclosed flare, which has been used since December 2012 and will continue being used while there is insufficient volume and quality to justify the investment made in the electricity generation system. This flaring will also be used when the LFG flow exceeds the capacity of the generation system or when the electricity generation system is not in operation (for example, in case of maintenance or breakdowns).

Based on the amount of waste to be disposed of and its composition, the overall generation of biogas is estimated at 176 million m³ during the first 7 years of the project. Part of this gas will be flared and approximately 70 million m³ will be used for electricity production.

Regarding electricity generation, the project will use modular units, each one including 3 generators; the capacity of each generator is 1,415 MW (with a resulting overall combined capacity of 4,245 MW).

The total investment required to implement the project is estimated at more than US$ 15,000,000, most of it related to the electricity generation component, which includes engines/generators, plant construction and its connection (US$ 7,000,000) and pipeline, well heads, perforation, and the biogas plant itself, which includes blowers, pretreatment and flare.

The project is beneficial, insofar as it avoids landfill methane being released to the atmosphere. During its first seven years of operation, the project is estimated to reduce up to 1 million tCO₂e. By 2013, it could reduce
up to 143,543 tCO₂e in 2013, peaking at about 180,673 tCO₂e in 2018. The estimated annual average is of 155,112 tCO₂e.

The project will improve local health and environmental conditions. With the operation of CTR Candeias landfill gas recovery and use project, the risk of diseases related to the local environment will be significantly reduced, as well as the risk of explosion during the landfill’s operation. The project has another positive, yet limited, impact on local employment, through the hiring of professionals to work in the daily operations of the landfill.
The current report was prepared by MGM Innova (MGM) for ABRELPE, the Brazilian Association of Public Waste Management Companies, as part of the agreement for the development of the Brazilian Greenhouse Gas (GHG) and Energy Atlas. This agreement is composed of four main phases, as follows:

1. Diagnostics;
2. Analysis of three opportunities for biogas capture and use;
3. Analysis of the Carbon Market;

This report refers to the above Phases 1, 2 and 3. It includes an analysis of waste generation and disposal in Brazil, as well as an analysis of GHG generation, and mitigation procedures through capture, flaring and utilization of biogas on a regional and country-specific basis.

The report also includes an analysis of three opportunities for biogas capture, flaring and use projects in sanitary landfills in Brazil.

Most of the information used in this report was provided by ABRELPE and other sources, duly referenced. MGM cannot guarantee the accuracy of the information provided by third-parties, nor that of the conclusions based on such information.

The ABRELPE team who provided support in the development of this report is the following:

CEO: Carlos R. V. Silva Filho
Coordinator – Technical Department: Adriana Z. G. Ferreira

The following MGM team was involved in the project:

Project Manager: Mauricio Gonzalez
Senior Technical Expert: Gautam Dutt
Project Engineer: Gabriela Pacheco
Senior Technical Reviewer: Alfredo Nicastro
Local Support: Stefan David/Sandra Apolinar

Graphic Design: Grappa Editora e Comunicação