

Waste to Energy for More Effective Landfill Site Management

SUMMARY

By 2025, global urban municipal solid waste (MSW) is projected to increase to 2.2 billion tonnes per year. Infrastructure to reduce, re-use, recycle and recover waste is often absent, poorly established, or largely informal. Where solid waste management (SWM) practices are in place, MSW often gets disposed in landfill sites. However, conventional landfill sites usually fail to exploit the potential of waste as an energy resource. The anaerobic decomposition of organic waste in landfill sites also leads to the release of methane, a greenhouse gas (GHG) over 20 times more effective in trapping heat in the atmosphere than carbon dioxide (CO₂) over a 100-year period. Methane released from landfill sites to the atmosphere is not usually controlled or captured, and as such has been one of the most negative side effects of landfill sites. Methane can, however, be captured and converted to CO₂ through combustion. A landfill site in Belo Horizonte, operational for 32 years, is an interesting example of the different landfill site stages. Although it was once the largest single source of GHG emissions in the city, GHGs from the landfill site have been reduced substantially and since its closure in 2007, the Municipal Waste Treatment Centre has made it into a waste-to-energy facility. The landfill capture and power generation facility have been fully operational since 2010.

Figure 1: Aerial view of the landfill site along the BR.040 in Belo Horizonte (district Jardim Filadélfia).



INTRODUCTION

THE WASTE CHALLENGE

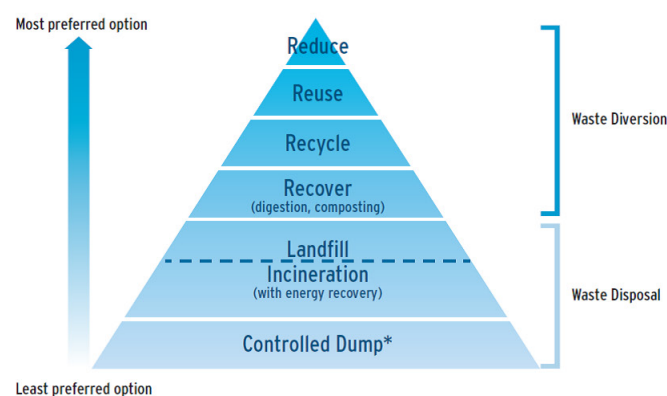
With rapid urbanisation and growing levels of disposable incomes, urban households are producing more waste than ever before. Global urban MSW has been estimated at 1.3 billion tonnes per year, according to a recent World Bank report (World Bank, 2012). By 2025, global urban MSW is projected to increase to 2.2 billion tonnes per year. At the same time, low-income countries spend most of their SWM budgets on waste collection, with only a fraction going toward disposal. Solid waste is a large source of methane, a powerful GHG and when uncollected contributes to flooding, air pollution and public health impacts. The World Bank highlights:



- » Landfilling and thermal treatment of waste are the most common methods of MSW disposal in high-income countries.
- » Most low- and lower middle-income countries dispose of their waste in open dumps.
- » Several middle-income countries have poorly operated landfills; disposal should be classified as controlled dumping.

Infrastructure to reduce, re-use, recycle and recover waste is often absent, poorly established, or largely informal. Where SWM is in place, MSW often gets disposed of in landfill sites. Landfill sites, however, are also a burden and do not provide a long-term sustainable option (see figure 2). Landfill sites in the United Kingdom, for example, account for around 3% of total GHG emissions. In addition, conventional landfill sites usually fail to exploit the potential of waste as an energy resource.

Figure 2: Waste hierarchy



Source: World Bank (2012)

(*) As a minimum waste should be disposed at a "controlled dump", which includes site selection, controlled access, and where practical compaction of waste.

Re-using waste for energy production. While more desirable waste diversion practices should be considered first (see figure 2), non-toxic waste can also be considered as a resource to produce energy. This can help to address local and regional energy security concerns (e.g. producing local energy), and mitigate climate change and local waste disposal challenges. There are two principle waste-to-energy approaches:

- » **Incineration of waste.** Waste can be used as a combustible fuel to produce energy. While incineration can have other environmental drawbacks (e.g. release of harmful particulates), it can represent an easy and cost effective solution for reducing the amount of waste accumulating in landfills, while generating energy.
- » **Landfill gas capture to produce energy.** Landfill sites with decomposing organic matter (including sites closed to receiving new wastes) release gases (mostly methane (CH_4)). Methane is a potent GHG, as well as a combustible natural gas. Capturing this landfill gas offers a cost-effective strategy to reduce GHG emissions by using it as a resource for energy production.

Organic matter in landfill as a renewable energy source. The anaerobic decomposition of organic waste in landfill sites leads to the release of methane. Methane is over 20 times more effective in trapping heat in the atmosphere than CO_2 over a 100-year period. Conventionally, methane released from landfill sites to the atmosphere has not been controlled or captured and is one of the negative side effect of landfill sites.

Methane can, however, be captured and converted to CO₂ through combustion. Since the biodegradable part of waste comes from plants, food leftovers, natural agricultural wastes, etc., which absorbed CO₂ during their growth, the combustion and decomposition of the organic matter is considered to be carbon-neutral and renewable. This, in principal, can also be applied to other waste-to-energy or anaerobic digestion plant facilities, which typically combust renewable organic matter or biogas from the decomposition process (see case examples). The methane from landfill sites or biogas can be used as a fuel in gas engines, gas turbines or steam boilers for heat, electricity or mechanical energy (e.g. transport). Using MSW in such a manner contributes to integrated SWM.

Potential roles for local government. Waste is an important and urgent public issue and is usually strongly interlinked with public health concerns. In many cases, MSW lies within the direct local government's administrative responsibilities as they are typically responsible for ensuring that waste is collected, processed and disposed. Local governments can provide regulation, guidance and training to waste producers and work to bring relevant stakeholders together to establish effective solutions. They could also invest in pilot or demonstration projects, and upgrade or request upgrades of facilities. In the process, municipal waste planners can promote integrated SWM practices.

While many local governments have only recently started to include energy generation and GHG emission reduction practices into their waste management strategies, the principal goal should always be to reduce, re-use, recycle and recover waste. This implies that the creation of landfill sites should be avoided from the outset. Organic matter for example, could be banned from landfill sites in favour of other anaerobic digestion plants. This would force local waste agencies to separate organic waste and re-use it as a renewable resource (e.g. energy, fertiliser, etc.).



CITY IN FOCUS:
Belo Horizonte,
Brazil
Population
2.4 million
(2010)

CONTEXT

ADDRESSING WASTE MANAGEMENT IN BELO HORIZONTE

Sustainable development has been an important agenda in Belo Horizonte, the third biggest city of Brazil. Belo Horizonte produces 3,580 tonnes of MSW and 28 tonnes of hospital waste every day. Waste management in Belo Horizonte falls under the jurisdiction of the Municipal Department of Urban Cleaning (Superintendência de Limpeza Urbana (SLU)).

Belo Horizonte has been pro-active in developing SWM practices through a series of activities, including an Integrated Solid Waste Management Model in 1993. Activities have included waste separation at sources, selective collection of recyclable waste (paper, plastic, metal and glass), and the creation of several organisations such as the *Construction and Demolition Waste Recycling Programme*, the Clean Urban Community Agents (organisation of workers, sweepers and collectors to improve their working conditions), and the *Composting Programme* and *Programme for Tyre Collection*. It has also piloted and operated a landfill gas capture scheme.

In 2006, the Municipal Department for Environment established the Municipal Committee on Climate Change and Eco-Efficiency (CMMCE). The committee is composed of representatives from the municipal and the state government, civil society, non-governmental organisations, the private sector and academia. Related policies are reinforced by *Law no. 10.175/11* introduced in May 2011. This law provides a Municipal Policy for Climate Change Mitigation. It includes a GHG reduction target of 20% by 2030 compared to 2007.

DESCRIPTION OF ACTIVITIES

PHASE 1: THE FIRST SANITARY LANDFILL IN BELO HORIZONTE (1972 - 1989)

In 1972, the local government of Belo Horizonte created the first sanitary landfill in the city along the highway (BR 040) in the district Jardim Filadélfia. The site selection of the landfill was based on studies developed for the first Master Plan for Urban Cleaning in Belo Horizonte. The area was declared public by

the *Municipal Decree No. 2303* of 18 December 1972, and the municipal landfill started operation in February 1975. This site, named the Municipal Waste Treatment Centre (Centro de Tratamento de Resíduos Sólidos (CTRS)), operated for 14 years as a conventional landfill in accordance with the respective rules.

PHASE 2: FIRST TRIAL AS A WASTE-TO-ENERGY LANDFILL (1989 - 1995)

Operation of the CTRS as an “energy landfill” started in 1989 with the capturing and treating of landfill methane. The biogas was used as a clean fuel for the SLU municipal vehicle fleet and the local electric utility, as well as for a few private taxis and a hotel situated nearby.

The implementation and operation, as well as the distribution of the recovered methane was conducted by Companhia de Gas de Minas Gerais (GASMIG), a subsidiary company of the state energy utility Companhia Energética de Minas Gerais (CEMIG). These activities continued until December 1995, when SLU ordered the closure of the biogas collection facility and removed the machinery. The closure was based upon observations that the volume of biogas produced in the collecting basins had decreased. Plastic garbage bags were non-biodegradable, which interfered in the decomposition and biogas collection.

PHASE 3: DIFFERENT TECHNIQUES TO SOLVE THE WASTE PROBLEM (1994 - 2007)

In 1994, the SLU contracted a consulting company to recommend a solution to reduce the environmental impact of the landfill site and to extend its lifetime. The landfill was approaching its maximum capacity. The resulting activities included different stocking techniques to optimise the use of the landfill space and the practice of bioremediation techniques (use of micro-organism metabolism to remove pollutants). The programme lasted until 2001, when it was ascertained that the process did not have the expected results in terms of accelerating the decomposition and stabilisation of organic material. Other measures were taken to expand the capacity of the landfill and to treat particularly dangerous waste.

A study was conducted to identify a location for a new landfill site. As a number of challenges emerged in finding a new site, it was decided to continue using the existing site until its closure. Belo Horizonte had to deal with a shortage of suitable land given the special location requirements for a new landfill site.

The landfill site finally closed in December 2007, after being open for 32 years, to conventional operations. Towards the end of 2006, more than 17.4 million m³ of waste had been deposited in the landfill. The maximum landfill height was about 64 meters. Although the landfill site could have potentially operated for another two years, it was decided to close the site to accommodate the concerns from nearby residents (bad odours, heavy truck traffic in the region, dust, etc.) and pressure from the national environment agency. The fact that the landfill site had reached its full capacity resulted in two key challenges. First, alternative solutions for managing the urban waste had to be found, and second, the heritage of the landfill site would remain a burden to the quality of the local and global environment.

PHASE 4: WASTE-TO-ENERGY IN THE CTRS FROM 2007

A waste-to-energy approach was identified for the site. The collection and exploitation of the landfill biogas offered the possibility of addressing some of the existing environmental challenges, while also contributing to the city’s growing energy needs.

In Brazil, most landfill sites use an open drainage system, where a flame burns the escaping biogas (*i.e.*, flaring). In Belo Horizonte, the experts realised the potential to capture the landfill gas with new technologies. In 2007, the local government launched a tender for a specialised company to capture the landfill biogas. One requirement was that it be linked with the certification and marketing of carbon credits under the Clean Development Mechanism (CDM), in accordance with the United Nations Framework Convention on Climate Change’s Kyoto Protocol. The public process called upon national and international companies to present the most qualified and cost effective project to equip and manage the biogas production and utilisation centre.

The rights to use the biogas generated at CTRS was granted to the Italian company Asja Ambiente Italia SpA for a period of 15 years (2008-2023), while the biogas collection project proposal was designed for

10 years. Their project foresaw the creation and management of a plant with 1) biogas collection and transmission; 2) biogas suction and control; and 3) biogas treatment, electricity generation and flare combustion.

In December 2008, the project's infrastructure construction started and by the beginning of 2009, the first landfill gas collection wells were drilled. By the end of 2009, the landfill gas collection and flare combustion plant was installed. In 2010, the plant became fully operational. The project was given the authorisation to install and operate an energy plant of maximum 5 MW capacity, which equated to a maximum annual generation of 43,800 MWh.

An agreement was signed with the municipal authorities that the generated electricity would be directly sold to the energy utility (CEMIG) under a contract of four years, which would be distributed to consumers through the city's electricity network. The biogas capturing facility was also registered in 2011 under the CDM, thereby benefiting from carbon revenues through Certified Emission Reductions (CERs).

RESULTS

Additional energy generation. The energy produced by processing and burning biogas at the CTRS is commercialised through the local electricity utility provider CEMIG on a contract basis for four years for the installed capacity. In 2011, the plant had a gross electricity production of 30,400 MWh. The biogas plant consumed only 2,900 MWh in 2011 for maintenance and operation. Thus, around 28,000 MWh of electricity was supplied to the electricity grid. This corresponds to the electricity consumption of approximately 30,000-35,000 people.

Centro de Tratamento de Resíduos Sólidos* (CTRS)

The landfill site is 114 hectares large. The CTRS occupies an area of approximately 65 hectares. Its operations include capturing of methane from the old landfill site, generation of electricity from the biogas, provision of recycling programmes and activities to promote education and public health. The Biogas Processing and Utilisation Centre is managed by Asja Ambiente. The other facilities are managed by the SLU. CTRS represents one of the first such initiatives in the Brazilian State of Minas Gerais.

Since 2007, the CTRS operates following different facilities:

- » The composting plant which processes the organic waste that has been selectively collected at fairs and markets.
- » The construction waste recycling unit which processes debris generated in the construction sector, producing materials such as sand or synthetic gravel used to pave streets.
- » The machinery maintenance and equipment division, which is responsible for the maintenance of trucks and light vehicles.

- » The seedling station, which includes a facility to grow seedlings and plants used for the environmental restoration of the landfill site.
- » The environmental education unit which provides education and tours. Up to 1,200 students visit every month to learn about reusing recyclable materials amongst other matters.
- » The healthcare waste unit, which receives waste from health services for special processing.
- » The tyre recycling unit, which receives and temporarily stores tyres for recycling.
- » The waste shipment unit, which has been responsible for allocating waste generated in Belo Horizonte to other landfill sites since the local landfill was closed in 2007. Currently, the waste generated by the city is transported to the landfill in Sabará.
- » The small volumes unit, which is responsible for receiving small amounts of regional construction waste and other debris (e.g. tyres, scraps) to prevent their unauthorised dumping.

(*) Municipal Waste Treatment Centre

Table 1. Results scenario for the landfill methane capture for the selected period 2010-2016

Year	Methane destroyed/ combusted through project in tCH ₄ /y (UNFCCC tool)	CO ₂ Emission Reductions in tCO ₂ e/y	Net quantity of electricity exported MWh/y
2010	15,079	237,473	27,510
2011	12,285	194,588	27,510
2012	10,224	162,409	25,250
2013	8,672	137,586	20,983
2014	7,480	118,506	17,704
2015	6,543	103,515	15,127
2016	5,790	91,475	13,057

Source: <http://cdm.unfccc.int/Projects/DB/SGS-UKL1267696608.78/view>

Reduction of tonnes of CO₂ equivalent (tCO₂e). The landfill site used to be among the largest single sources of GHG emissions in Belo Horizonte. GHGs from the landfill site have substantially reduced since 2009. Table 1 shows the projected scenarios for the amount of methane destroyed, CO₂e emission reductions and the net quantity of electricity supplied to the grid between during the CDM crediting period - 2010 and 2016 (the entire project period is mid 2009 until 2019).

Social achievements. The project has had a positive impact on the local community. Complaints from residents, e.g. over bad smells, have receded and the risk of explosions and fire has significantly dropped. In addition, a highly-qualified team of engineers and operators were hired and trained to run the project.

COSTS AND FINANCING

The waste-to-energy management of the landfill site was outsourced by the City of Belo Horizonte to Asja Ambiente. This group paid an advance to the municipality for the rights to exploit biogas for 15 years. Major initial investment for Asja Ambiente included the purchasing of generators, the capture system, transportation, purification, as well as the analysis and measurement of biogas.

The city receives a fee equal to 6% of the value of the electricity that is sold to the electric utility CEMIG. An additional source of income for the municipality is derived from the sale of around 1.3 million CERs over a 10 year crediting period under the CDM.

LESSONS LEARNT FOR REPLICATION

Identifying and harvesting unused potential. By continuously re-examining and innovating waste management practices of a landfill site, untapped or under-used potential can be harvested beyond its conventional lifespan. Changes to a landfill site provide an opportunity to re-design its function beyond simple closure and contribute to integrated SWM strategies. Methane can be captured for energy production, the space can be used for other waste management activities, and the site can serve for educational purposes to reduce, re-use, recycle and recover waste. With in-

Table 2: Selected financial parameters of the methane landfill capture project for 2009-2019.

Annual average output (CERs)	134,160
Average annual production (MWh)	17,479
Total CERs to trade (over 10 year period)	1,341,603
Total electricity delivered to the grid (MWh)	174,785
Expected sale of electricity (Euro/MWh)	52.87
Average installed capacity (MW)	4.05
Total investment (Euro)	4,582,015
Lifetime of the project (years)	10
Crediting period (years)	10
Depreciation rate	10%

Source: <http://cdm.unfccc.int/Projects/DB/SGS-UKL1267696608.78/view>

volvement of the private sector, appropriate technologies can be used to capture methane towards profitable returns and in the process improve the local and global environment.


Considering local geography and climate. It is crucial to carry out studies on the potential of biogas generation, focusing on the specific geographical characteristics and the climate condition of each locality. Climate differences as well as seasonal and daily temperature variations, play an important role in determining the decomposition process and rate. This, in turn, affects the amount of electricity which can be generated.

Feasibility studies and potential for reproduction. It has been estimated that collection of methane is only profitable in medium and large landfills (*i.e.* cities with over 100,000 inhabitants). However, the feasibility of a waste-to-energy project also depends on other conditions. The waste of every nation, region and city has its own characteristics, *e.g.* the share of organic waste. A careful analysis of the physical and biological characteristics of the waste generated in a community or region as well as the design and the landfill operating conditions are fundamental for the success of a project. An investigation into the potential for capturing methane from a landfill site can go hand in hand with a wider investigation into the separating of organic waste towards organic digestion for energy production amongst others.

Energy production from landfill methane to achieve several goals. Using biogas from landfill sites to generate electricity and heat offers an important contribution to sustainability. Landfill gas capture allows for mitigation of the impact of landfill sites on the environment. Some benefits include:

- » Environmental and social conditions of the citizens living in the area are improved, as bad odours and poisonous emissions are reduced.
- » The community's carbon footprint from landfill sites is reduced.
- » The dependency on energy generated from fossil fuels is reduced.

Carbon credits in the international market. The exploitation of biogas in large treatment units also allows for the negotiation of carbon credits in the international market. This can provide an additional revenue source for projects located in respective countries (UNFCCC Non-Annex 1 countries). It can also provide an additional market-based incentive for public-private partnerships.



Re-using wastewater for energy production and water saving, Ratnagiri, India (population 1.6 million)

An effluent treatment plant was installed in Ratnagiri, a district in Maharashtra about 400 km from Mumbai in order to treat wastewater from a seafood processing plant for the generation of biogas. The plant generates 13,000 m³ of biogas daily, replacing 4.7 kiloliters of oil from furnaces per day. The effluent is treated in an anaerobic digester and further processed for re-using the wastewater to reduce water consumption in the plant. During the treatment of wastewater, biogas is generated with a high percentage of methane. The gas is converted into thermal energy for the plant's own requirements. Not only is water consumption and energy use reduced, but the closed system prevents large quantities of methane, a powerful GHG, from being emitted into atmosphere. This is a joint project between the Ministry of Environment and Forests in India and Gadre Marine Export Pvt. Ltd.

Source: ICLEI, UN-HABITAT and UNEP 2009, Sustainable Urban Energy Planning, A handbook for cities and towns in developing countries

Landfill Gas to Electricity Project, eThekweni (Durban), South Africa (population 3.5 million)

In March 2009, the eThekweni Metropolitan Municipality partnered with national and international actors to put in place a project under the framework of the UNFCCC's CDM. The project aims to enhance the collection of methane at three landfill sites in the municipality. The methane recovery has been taken up at two of the planned sites, for a total installed capacity of 7.5 MW. The electricity from both sites is delivered to the eThekweni Municipality grid, based on a power purchase agreement for 10 years with options for two additional 5-year extensions. Durban Solid Waste, the municipal agency responsible for management and operation of multiple landfills in the eThekweni metropolitan area, is functioning as the technical advisor and the operational entity of the project.

Source:ICLEI, UN-HABITAT and UNEP 2009, Sustainable Urban Energy Planning, A handbook for cities and towns in developing countries.

kzenergy (accessed Nov 2012), Durban Landfill-Gas to Electricity Project, www.kzenergy.org.za/

Biogas from sewage for public buses, Lille, France (population 0.2 million)

The Urban Community of Lille (CUDL) is a public inter-municipal co-operation body that gathers 87 local authorities from the Nord-Pas-de-Calais Region, France. CUDL's competencies include the provision of services in the following areas: town planning, road infrastructure, mobility and parking facilities and urban transport systems for passengers. By the end of 1990, CUDL launched a project, the first of its kind in Europe, to use the biogas produced by the Marquette sewage plant in the suburbs of Lille to power urban transport buses. In 1990, 80% of the daily 15,000 m³ of biogas produced by the wastewater treatment plant (equal to 6,000 liters of petrol every day) was used to supply the treatment plant with heat and power. The remaining 3,000 m³ was wasted. CUDL decided to purify this unused waste to produce daily 1,200 m³ of biogas usable as fuel in public transport. The first bus operating on such biogas was introduced in March 1994. Currently, 50% of the municipal bus fleet is biogas-fuelled. Lille's example has been copied in many parts of the world.

Source:Energie-Cités (2008), Buses Powered by Biogas Produced in the Municipal Wastewater Treatment Plant - Lille CU, France, (accessed Nov 2012), www.energie-cites.org/

Further readings:

See additional relevant case studies at www.iclei.org/casestudies, for example:
122 - Belo Horizonte's steps towards a new solar energy legislation, Belo Horizonte, Brazil
107 - Turning pollution into profit: the Bandeirantes Landfill Gas to Energy Project - Sao Paulo, Brazil
60 - Waste Management Through Community Partnerships - Belo Horizonte, Brazil

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UNFCCC (accessed October 2012), CDM, Project Cycle Search, Project 3464: Exploitation of the biogas from Controlled Landfill in Solid Waste Management Central - CTRS / BR.040 <http://cdm.unfccc.int/Projects/DB/SGS-UKL1267696608.78/view>
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