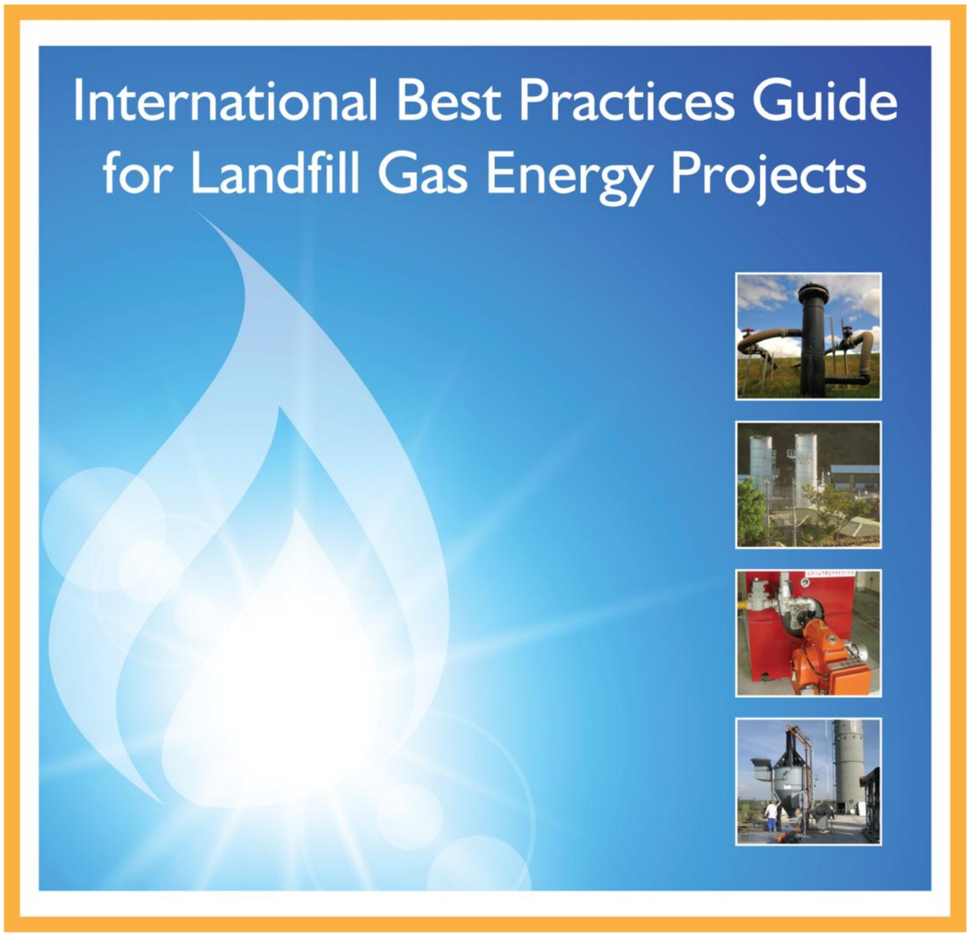
Global Methane Initiative

International Best Practices Guide for Landfill Gas Energy Projects

EPA United States Environmental Protection Agency

ISWA International Solid Waste Association

Global Methane Initiative



U.S. Environmental Protection Agency

2012

Acknowledgments

The U.S. Environmental Protection Agency (EPA) acknowledges and thanks the following individuals who conducted an expert review of this document:

- Ricardo Cepeda-Marquez, William J. Clinton Foundation, Mexico
- Daniel Fikreyesus, EchnoTech, Ethiopia
- Hamza Ghauri, Alternative Energy Development Board, Pakistan
- Derek Greedy, International Solid Waste Association, Landfill Working Group, United Kingdom
- Falko Harff, CarbonBW Colombia S.A.S., Colombia
- Basharat Hasan Bashir, Alternative Energy Development Board, Pakistan
- Piotr Klimek, Oil and Gas Institute, Poland
- Adrian Loening, Carbon Trade Ltd., United Kingdom
- Mauricio Lopez, Caterpillar Inc., United States
- Karen Luken, William J. Clinton Foundation, United States
- Alfonso Martinez Munoz, PASA Mexico
- Yuri Matveev, Renewable Energy Agency, Ukraine
- Erika Mazo, CarbonBW Colombia S.A.S., Colombia
- Ricardo Rolandi, Asociación de Residuos Sólidos (ARS), Argentina
- Horacio Terraza, Inter-American Development Bank, Argentina
- Richard Tipping, Chase Environmental, United Kingdom
- Goran Vujic, Serbian Solid Waste Management Association, Serbia
- Andrew Whiteman, Wasteaware/Resources and Waste Advisory Group, United Kingdom

EPA also thanks the following staff and contractors who contributed to the development of the guide:

U.S. EPA Climate Change Division, Landfill Methane Outreach Program (LMOP)

- Tom Frankiewicz
- Swarupa Ganguli
- Chris Godlove
- Victoria Ludwig

Contractors to EPA LMOP

- Eastern Research Group, Inc.: Amy Alexander, Stacy DeGabriele, Brian Guzzone and Amanda Singleton
- SCS Engineers: Brent Dieleman, Chad Leatherwood, Sandra Mazo-Nix, Dana Murray, Eric Peterson and Alex Stege
- Tetra Tech EM Inc.: Chris Bachman, Donna Boysen, Austin Oelschlager and Cathy McGirl
- MGM Innova
- Organic Waste Technologies (HK), Ltd

The International Solid Waste Association (ISWA) is an international, independent and non-profit making association, working in the public interest to promote and develop sustainable waste management worldwide. The ISWA Working Group on Landfill is specifically focused on the appropriate design, construction, regulation and management of landfills, both for advanced and developing nations.

Executive Summary

Solid waste management is usually one of the most labor- and cost-intensive services provided by local governments in developed and developing countries, and local government officials often face challenges in identifying the most appropriate solid waste management technologies and implementing solid waste management projects. Landfill gas energy (LFGE) is a small but important component of an integrated approach to solid waste management given that the use of landfills continues to remain the predominant method of solid waste disposal (SWD) in most countries. Many LFGE systems have been built, only to close shortly after costly start-up, operations and maintenance. As a result, helping local governments choose appropriate solid waste management strategies and technologies is critically important.

Best Practices to Overcome Barriers to Successful LFGE Projects

Use of the guide will help stakeholders address the five most common barriers:

- Resolving flaws in solid waste final disposal site design and operation
- Designing and operating successful LFG collection and control systems
- Estimating the volume of LFG available to the project
- Selecting appropriate technologies for energy recovery
- Securing financing for the project

Global Methane Initiative's (GMI) *International Best Practices Guide for Landfill Gas Energy Projects* provides a broad overview of the development process for LFGE projects in international settings and presents the technological, economic and political considerations that typically affect the success of LFGE projects. The goal of the guide is to encourage environmentally and economically sound LFGE projects by connecting stakeholders with available information, tools and services. The guide is not intended to provide a step-by-step protocol for project development.

Audience

The guide provides valuable information for representatives of national, regional and local governments, landfill owners, energy service providers, corporations and industries, and representatives of not-for-profit organizations. These and other stakeholders will benefit from information provided in this guide as they work together to develop successful LFGE projects. Less familiar stakeholders will learn about the basics of integrated solid waste management and be introduced to general concepts and considerations of LFGE projects, including examples of existing LFGE projects and access to key resources. Experienced, more technical stakeholders will be updated on technical considerations regarding site design and operation, provided insights into models for estimating landfill gas (LFG) generation and collection, and can investigate the many resources and tools identified throughout the guide that will assist them in making decisions about LFGE projects.

Best Practices

The guide identifies best practices for the major components of a LFGE project as discussed below.

Basic Concepts of Integrated Solid Waste Management. Rapid population growth and high rates of urbanization, coupled with increasing prosperity in developing countries, require a serious examination of the waste management process. Incorporating integrated solid waste management (ISWM) and LFGE best practices can help to protect human health and the environment from the dangers of improperly managed and discarded waste. Finding the proper mix of practices to meet a local community's means and needs will help ensure a healthier population and environment.

Solid Waste Disposal Site Design and Operational Considerations. Improving the conditions of an SWD site to the standard of a properly designed and operated sanitary landfill will likely improve the collection of LFG. It is important that stakeholders understand how the various components of an SWD site affect the generation of LFG, the methane content, and the collection efficiency of the LFG collection system, including how common flaws in design and overall operation can affect LFG generation. Implementing training opportunities can help to reduce these design and operational flaws. Well-designed and operated sanitary landfills will generate LFG that can be feasibly collected and used and provide cost savings over the life of the project.

Design, Construction and Operation of Landfill Gas Collection and Control Systems. The foundation of any LFGE project involves the design, construction and operation of a landfill gas collection and control system (GCCS). GCCSs require proper engineering design, construction and operation by trained personnel to maximize intended benefits. While the use of proper techniques and quality assurance procedures during construction help to ensure proper system operation and reliability, it is the operation of the GCCS that determines the success of the LFGE project. With periodic monitoring and adjustments to the GCCS, stakeholders will be able to adapt to constantly changing SWD site conditions.

Landfill Gas Energy Utilization Technologies. The overall feasibility of an LFGE project for a particular landfill depends on numerous technical considerations, such as waste composition and volume, quality and quantity of LFG, and availability and location of a suitable end user. Understanding, evaluating and selecting the appropriate LFGE utilization technologies is essential for the overall feasibility and success of LFGE projects. Proven and emerging technologies offer practical solutions to effectively implement LFGE projects for direct-use and electricity generation, including the treatment of LFG to remove moisture, particulates and other impurities.

Market Drivers for LFGE Projects. It is important that stakeholders recognize and understand how policy and market drivers affect the development of LFGE resources and support the long-term sustainability of LFGE projects. Policy and financing mechanisms are central to assessing the financial viability of LFGE projects. While market drivers and financing mechanisms will vary by country and region, the demand for renewable energy and cost-competitiveness of that energy compared with alternatives should be assessed carefully during the planning stages of an LFGE project to ensure that the most effective combination of revenue opportunities is harnessed.

Landfill Gas Modeling. Estimating the volume of LFG generation from a landfill is a critical component of project assessment and conceptualization because the collection projections are used to estimate the size of the project, expected revenues, project design requirements and capital and operating costs. However, accurately projecting the total LFG and methane generation for a landfill can be difficult for many stakeholders. It requires selection and use of an appropriate LFG model among several options, consideration of local conditions that affect LFG generation, and an understanding of the uncertainty inherent with LFG modeling. The value of LFG estimates also depends on the quality of data used in the model; proper consideration of factors such as annual waste composition, disposal rates and estimated growth rates; and the participation of an experienced LFG modeler.

Project Economics and Financing. The economic viability of a LFGE project relies heavily on identifying financial mechanisms to promote the development of LFGE resources. Options vary by country, but may include tax incentives, public-private partnerships, bond financing, direct municipal funding, loan guarantees and grants. It is important that stakeholders understand the range of financial mechanisms available for their LFGE project; evaluate carefully the economic feasibility of options, including non-price factors; and select the most viable project option to meet stakeholder goals.

Contents

Abbreviations

Units of Measure, Constants and Symbols

Btu	British thermal unit
cm	Centimeter
CH_4	Methane
CO	Carbon monoxide
CO_2e	Carbon dioxide equivalent
^oC	Degree Celsius
DOC	Degradable organic carbon
DOC_f	Fraction of DOC that decomposes
ERU	Emission reduction unit
ft^3	Cubic foot
H_2S	Hydrogen sulfide
ha	Hectare
hr	Hour
k	Methane generation rate constant
km	Kilometer
kPa	Kilopascal
kW	Kilowatt
kWh	Kilowatt hour
l/hr	Liters per hour
L_0	Potential methane generation capacity
m^2	Square meter
m^3	Cubic meter
m^3/hr	Cubic meter per hour
MCF	Methane correction factor
Mg	Megagram
MJ	Megajoule
mm	Millimeter
$MMTCO_2e$	Million metric tons of carbon dioxide equivalent
MW	Megawatt
N_2	Nitrogen
O_2	Oxygen
Psig	Pounds per square inch
tCO_2e	Tonnes of carbon dioxide equivalent
µm	Micrometer

Abbreviations and Acronyms

AD	Anaerobic digestion
C&D	Construction and demolition
CALMIM	California Landfill Methane Inventory Model
CAR	Climate Action Reserve
CDM	Clean development mechanism
CER	Certified emission reduction
CFR	Code of Federal Regulations
CHP	Combined heat and power
CIGAR	Covered In-Ground Anaerobic Reactor
CNG	Compressed natural gas
CQA	Construction quality assurance
CREB	Clean renewable energy bond
DUKES	Digest of United Kingdom Energy Statistics
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FGC	Fuel gas compressor
FiT	Feed-in tariffs
GCCS	Landfill gas collection and control system
GHCN	Global Historical Climatology Network
GHG	Greenhouse gas
GMI	Global Methane Initiative
HDPE	High density polyethylene
IBAM	Brazilian Institute of Municipal Management
IPCC	Intergovernmental Panel on Climate Change
ISWA	International Solid Waste Association
ISWM	Integrated solid waste management
ITC	Investment tax credit
JI	Joint implementation
JVETS	Japan’s Voluntary Emission Trading Scheme
LandGEM	Landfill Gas Emissions Model
LCFS	Low Carbon Fuels Standard
LCRS	Leachate Collection and Removal System
LFG	Landfill gas
LFGE	Landfill gas energy
LMOP	U.S. Environmental Protection Agency’s Landfill Methane Outreach Program
LNG	Liquefied natural gas
MCF	Methane correction factor
MDB	Multilateral development banks

MFI	Multilateral financial institutions
MRF	Materials recovery facility
MSW	Municipal solid waste
NGO	Nongovernmental organization
O&M	Operation and maintenance
OECD	Organisation for Economic Co-operation and Development
PBF	Public benefit funds
PDD	Project design document
PET	Potential evapotranspiration
PoA	Programme of activities
PPA	Power purchase agreement
PPE	Personal protective equipment
PPP	Public-private partnership
PTC	Production tax credit
PVC	Polyvinyl chloride
QA/QC	Quality assurance/quality control
REC	Renewable energy certificate
RES	Renewable electricity standard
RFP	Request for proposal
SWANA	Solid Waste Association of North America
SWD	Solid waste disposal
UK	United Kingdom
U.S. EPA	U.S. Environmental Protection Agency
US	United States
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	US Dollar
VCS	Verified Carbon Standard
WARM	Waste reduction model
WTE	Waste-to-energy

Introduction

GMI's *International Best Practices Guide for Landfill Gas Energy Projects* provides a broad overview of the development process for LFGE projects in international settings and presents the technological, economic and political considerations that typically affect the success of LFGE projects. The goal of the guide is to encourage environmentally and economically sound LFGE projects by connecting stakeholders with available information, tools and services. The guide is not intended to provide a step-by-step protocol for project development.

The guide provides valuable information for representatives of national, regional and local governments; landfill owners; energy service providers; corporations and industries; and representatives of not-for-profit organizations. These and other stakeholders will benefit from information provided in this guide as they work together to develop successful LFGE projects.

The guide is organized into seven chapters:

- Chapter 1 – Basic Concepts of Integrated Solid Waste Management
- Chapter 2 – Solid Waste Disposal Site Design and Operational Considerations
- Chapter 3 – Design, Construction and Operation of Landfill Gas Collection and Control Systems
- Chapter 4 – Landfill Gas Energy Utilization Technologies
- Chapter 5 – Market Drivers for LFGE Projects
- Chapter 6 – Landfill Gas Modeling
- Chapter 7 – Project Economics and Financing

A selection of case studies of successful LFGE projects in GMI Partner Countries is highlighted in Appendix A. Each case study includes a project summary and identifies benefits achieved and the barriers overcome during the project.

Appendix B presents health and safety considerations for construction and operation of LFGE projects.

Learn More About GMI

GMI is a voluntary, multilateral partnership that aims to reduce global methane emissions and to advance the abatement, recovery and use of methane as a valuable clean energy source. GMI achieves this by creating an international network of partner governments, private sector members, development banks, universities, and nongovernmental organizations (NGO) in order to build capacity, develop strategies and markets, and remove barriers to project development for methane reduction in partner countries. This guide advances the purpose and mission of the initiative by providing the tools and necessary information to stakeholders for the development of successful LFGE projects. Details about GMI are available at http://globalmethane.org.

Using this Guide

The guide is designed to highlight basic concepts and best practices related to LFGE projects. Because LFGE projects operate within a complex framework of political, legal, institutional and financial considerations, this guide does not offer a "one size fits all" approach to implementing best practices. Additional resources, examples and source materials that contain more comprehensive information are described in callout boxes and referenced in extensive footnotes. Readers are encouraged to visit the additional resources listed throughout the document to find specific details that may be relevant to individual projects and topics.

Some aspects of LFGE projects are not discussed in detail. In particular, the guide does not present specific details about governance issues and regulatory authorities because they differ widely among developed and developing countries and among different regions throughout the world. Similarly, limited cost information related to LFGE projects is provided because costs can vary significantly depending on several factors, including the cost of material, labor, import fees and taxes.

The guide includes references to international agreements, programs and mechanisms that are changing over time. For example, the Kyoto Protocol's market-based mechanisms for meeting greenhouse gas emission reduction targets, including the Clean Development Mechanism (CDM) and Joint Implementation (JI), are evolving; for the timing and purposes of this guide, consistent reference is made throughout to CDM and JI. Economic and regulatory factors that affect the viability of LFGE projects, including the availability of project funding through CDM and JI, also are evolving. These factors include the availability of trading markets for certified emissions reductions (carbon credits) and renewable energy standard regulations. Best practices for financing LFGE projects should be assessed carefully during planning stages because funding mechanisms will vary within and among countries and regions.

Disclaimer

The guide is not an official guidance document. Readers of the guide are encouraged to explore opportunities to use the best practices described in the following pages in accordance with applicable regulatory program requirements in their countries or municipalities. This document provides general information regarding LFGE projects. It does not address all information, factors or considerations that may be relevant. Any references to private entities, products or services are strictly for informational purposes and do not constitute an endorsement of that entity, product or service.

CHAPTER 1

Basic Concepts of Integrated Solid Waste Management

As the world's population surpasses 7 billion, the demand for access to improved sanitation steadily increases as a result of a burgeoning middle class in the developing world. Furthermore, by 2050, the world's population is expected to exceed 9 billion people.[1] Each year, the world's population generates more than 2 billion tons of waste; if society continues to move toward the current waste generation patterns of the wealthiest cities in high-income countries today, then by 2025, as much as 7 billion tons of waste could be generated each year.[2] Rapid population growth and high rates of urbanization, coupled with increasing prosperity in developing countries, require a serious examination of the waste management process (see Figure 1-1) and the role of integrated solid waste management (ISWM) to safeguard the environment against air and water pollution and residual waste, protect public health, and maximize the value-added elements (energy and recovered materials).

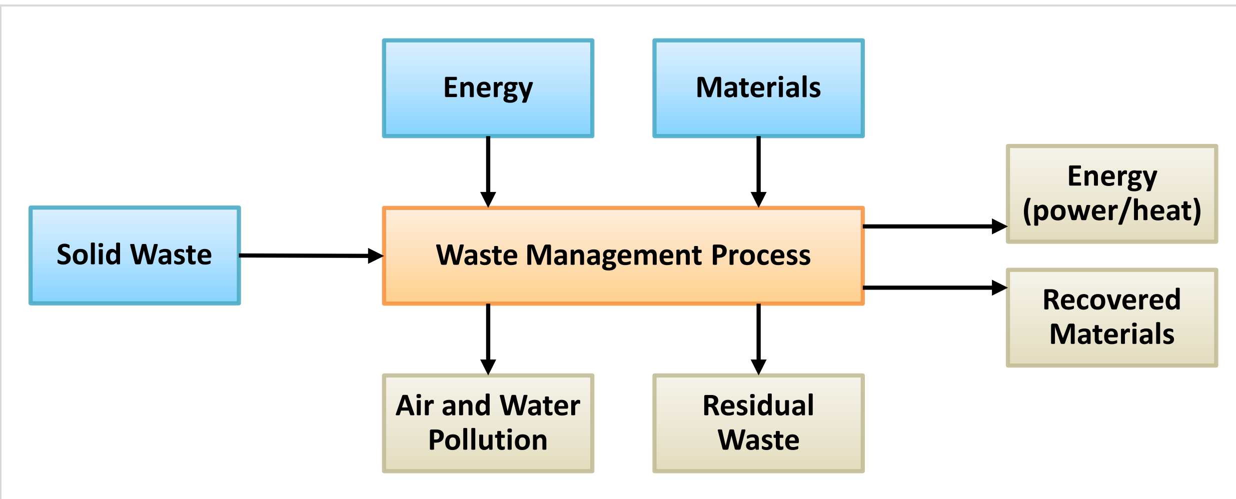


Figure 1-1. Life Cycle Inputs and Outputs of a Waste Management Process

Currently, between 30 and 60 percent of solid waste from cities in developing countries remains uncollected and ends up on the street or disposed of through open burning.[3] Waste is also dumped in bodies of water, which can affect water quality. Proper waste disposal is a major public health and environmental concern affecting rich and poor alike, and poses enormous challenges for growing cities and towns. However, as a result of rapid increases in population and urbanization, a growing number of developing countries are beginning to use some form of a solid waste disposal (SWD) site (open dump, controlled landfill or dump or sanitary landfill) to manage increasing waste generation (see Figure 1-2). Worldwide, the majority of waste is disposed of in landfills, which alleviates several public health concerns, but creates additional environmental considerations. Landfills provide an anaerobic environment for wastes to decay that causes the release of landfill gas (LFG) (composed of methane, carbon dioxide and volatile organic compounds), odors, and a host of other potential air, water and soil

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[1] Population Reference Bureau. April 2011. *World Population*. http://www.prb.org/.

[2] UN-HABITAT. 2010. *Solid Waste Management in the World's Cities, Water and Sanitation in the World's Cities*. http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2918.

[3] Ibid.

pollutants. The methane produced by landfills is of environmental significance because methane is a potent greenhouse gas (GHG), and its ability to trap heat in the atmosphere, called its "global warming potential," is more than 20 times greater than that of carbon dioxide.[4]

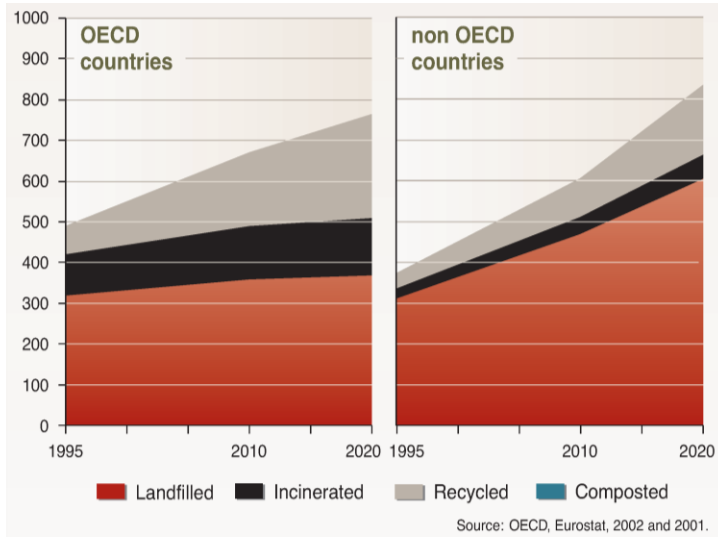


Figure 1-2. Increased Waste Generation in Developing Countries Predicted for 2020[5]

Globally, landfills are the third largest anthropogenic source of methane, accounting for approximately 11 percent of estimated global methane emissions or nearly 799 million metric tons of carbon dioxide equivalent (MMTCO$_2$e) emissions in 2010.[6]

The amount of methane created depends primarily on the composition, quantity and moisture content of the waste and the design and management practices of the landfill. Sanitary landfills, designed to maximize the anaerobic decomposition of waste, produce more methane than open dumps and other SWD options that allow for aerobic decomposition. As developing countries transition to controlled or sanitary landfills, methane emissions will rise as more waste is managed in a manner that is conducive to its generation. As a result, LFG collection and control measures are of increasing importance for managing these emissions. For example, in the 1990s, several major cities in South Africa experienced problems with increased demand for landfill capacity, which presented opportunities for both the collection of LFG from existing closed waste dump sites and the design of new sanitary landfill facilities that optimized LFG output for commercial purposes.[7] Several municipalities then implemented LFG recovery at better managed landfills and constructed sanitary landfills.

Moreover, the lowest cost and often the most expedient solution is SWD in uncontrolled landfills or dump sites (see Figure 1-3). As a result of the relatively high cost of sanitary landfills, cities tend to make little progress toward landfill implementation unless the regulatory framework and environmental agencies apply enforcement pressure.[8] Meanwhile, the availability of landfill capacity in many developed nations has been flat or steadily decreasing because of regulatory, siting and environmental permitting constraints on new landfills and landfill expansions. Under the European Union (EU) Landfill Directive, all EU member countries are required to reduce the amount of biodegradable waste sent to

[4] U.S. EPA. Methane: Science – Global Warming Potentials. http://www.epa.gov/methane/scientific.html.
[5] Gary Crawford, Veolia Environmental Services. 2011. *Incorporating the Waste Sector into a Country NAMA*. Presented at the GMI Partnership-Wide Meeting, Krakow, Poland, 13 October 2011. http://www.globalmethane.org/documents/events_land_101411_tech_crawford.pdf.
[6] U.S. EPA. 2011. *DRAFT: Global Anthropogenic Emissions of Non-CO$_2$ Greenhouse Gases: 1990–2030*. EPA 430-D-11-003. http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html.
[7] USAID. November 2004. *Draft Final: Study of the Market Potential for Recovered Methane in Developing Counties.* http://pdf.usaid.gov/pdf_docs/PNADK799.pdf.
[8] The World Bank. 2011. Analysis of Technology Choices. http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/EXTUSWM/0,,contentMDK:20239704~menuPK:497751~pagePK:148956~piPK:216618~theSitePK:463841,00.html.

landfills.[9] For example, the United Kingdom is obligated to reduce the amount of biodegradable waste sent to landfills based on the amount of this material landfilled in 1995 to 75 percent by 2010, to 50 percent by 2013, and to 35 percent by 2020.[10] As a result, new approaches to waste management are rapidly being written into public and institutional policies at local and national levels.

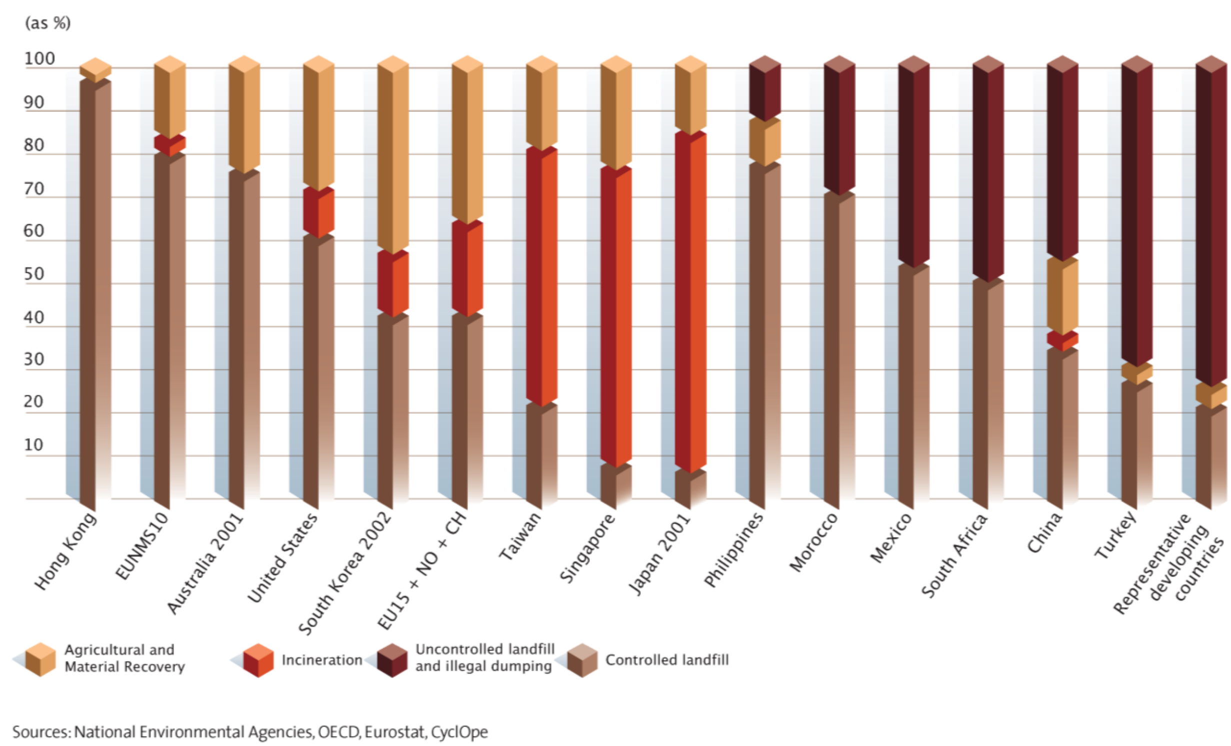


Figure 1-3. Municipal Waste Treatment Practices for Select Countries[11]

Solid waste management is usually one of the most labor- and cost-intensive services provided by local governments in developed and developing countries, and local government officials are frequently besieged by companies selling solid waste management technologies. Many of these technologies may not be appropriate, and officials may have limited experience for assessing a company's claims and technological viability. Inaccurate assumptions and inadequate planning by project officials have resulted in many systems being built, only to close shortly after costly start-up, operations and maintenance. Helping local governments choose appropriate solid waste management strategies and technologies is therefore critically important.

9 http://ec.europa.eu/environment/waste/landfill_index.htm. On this page, a reader can read a summary, then find the actual Directive.

10 International Solid Waste Association. 2011. State of the Nation Report, Chapter 3, England and Wales. May 2011 DRAFT.

11 Gary Crawford, Veolia Environmental Services. 2011. *Incorporating the Waste Sector into a Country NAMA*. Presented at the GMI Partnership-Wide Meeting, Krakow, Poland, 13 October 2011. http://www.globalmethane.org/documents/events_land_101411_tech_crawford.pdf.

Major Components of Integrated Solid Waste Management

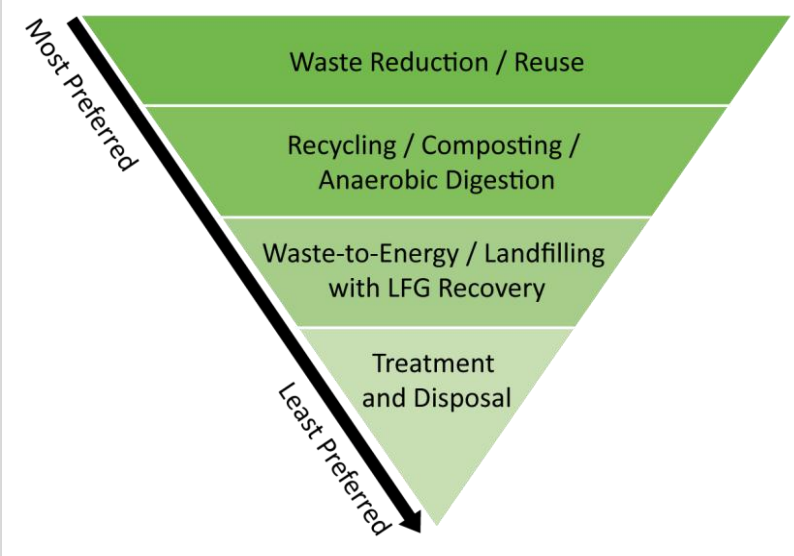


Figure 1-4. Preferred Components of Integrated Solid Waste Management

To address global waste management challenges, cities and relevant government entities have focused on developing and implementing a variety of ISWM strategies to tackle the long-term management of waste. The primary elements of ISWM are illustrated in Figure 1-4 and explained below.

Waste Reduction. Also referred to as source reduction, waste avoidance or waste prevention, this strategy is at the top of the waste management hierarchy. The U.S. Environmental Protection Agency (U.S. EPA) defines it as "the design, manufacture, and use of products in a way that reduces the quantity and toxicity of waste produced when products reach the end of their useful lives."[12]

Recognizing that the most effective way to reduce the impact of managing waste is to reduce the amount of waste that is generated, waste reduction aims to change the way products are made and used to minimize waste generation. For example, redesigning product packaging to eliminate excess or unnecessary materials reduces the amount of used packaging that is discarded. Waste reduction has the two-fold benefit of reducing raw material inputs and all of the cost and energy savings encompassed by this reduction, and reducing the volume of waste that needs to be managed and disposed of properly. Waste reduction conserves resources; reduces SWD costs and pollution, including GHG emissions; and teaches conservation and prevention.[13]

Reuse. Reusing products rather than discarding them after a single use reduces the demand for new products and the raw materials and energy inputs required to produce and transport them. Reuse conserves raw materials, reduces energy consumption and transportation emissions, and results in SWD cost savings and reduced GHG emissions. Many countries, for example, encourage the use of cloth bags instead of single-use plastic bags for groceries. However, there are limited numbers of waste materials that are appropriate for reuse or storage, which presents challenges for reuse.

Recycling. Recycling involves the collection of used materials and the reprocessing or remanufacturing of these materials into usable products or materials. Recycling materials such as metals, paper, plastics and wood saves GHG emissions by reducing the amount of solid waste requiring disposal and providing a substitute for virgin raw materials in product manufacturing. Using recycled materials also reduces GHG emissions from extracting, transporting, and processing virgin raw materials. Recycling also keeps valuable resources in use and out of the landfill. Recycling can be accomplished by separate collection of recyclable materials from households and businesses (source separation) or by separating mixed waste

12 U.S. EPA. August 1995. *Decision-Makers' Guide to Solid Waste Management, Volume II*. EPA 530-R-95-023. http://www.epa.gov/wastes/nonhaz/municipal/dmg2/.

13 International Solid Waste Association. 2009. *Waste and Climate Change: ISWA White Paper.*

to recover recyclable materials at a materials recovery facility (MRF) before transfer to a waste-to-energy facility or a landfill (see Figure 1-5). Recycling requires energy for transporting, reprocessing and remanufacturing materials, but typically consumes less energy than making products from virgin raw materials, resulting in net energy and emissions savings. Recycling also includes biological treatment of organic materials that can recover energy and generate usable agricultural products, such as composting and anaerobic digestion.

Figure 1-5. Metal Sorting at Materials Recovery Facility

Composting uses the natural decomposition of organic matter, such as food and yard wastes, to reduce the volume of waste and create compost, a humus-like material that can be added to soils to increase fertility, aeration and nutrient retention. Large-scale composting is typically done in windrows (long rows of crops) and sometimes in large-scale vessels that promote the aerobic decomposition of organic matter. Small-scale or backyard composting can be used as a method of managing food and yard wastes at or near their points of generation, keeping these materials out of the waste stream and serving as a form of waste reduction.

Anaerobic Digestion (AD) involves the conversion of biodegradable organic matter to energy by microbiological organisms in the absence of oxygen. The biogas produced in the digestion process is a mixture of methane and carbon dioxide and can be used as a fuel source for heating or electricity production.

Waste reduction, reuse and recycling all divert materials from the SWD stream and from landfills in many countries. While this reduction has many positive environmental benefits, it decreases the amount of LFG produced and subsequent availability for recovery and beneficial use.

Waste-to-Energy (WTE) is an effective means for converting waste to energy and significantly reduces the volume of waste and the proportion of organic matter that is placed in a landfill, which in turn reduces the production rates of landfill methane. Also referred to as waste combustion or incineration, WTE is the controlled combustion of waste in a modern furnace equipped with pollution controls that produces steam or electricity. Other technologies include gasification, plasma gasification and pyrolysis. Energy produced through WTE can help reduce the demand for fossil fuel combustion-derived energy, which reduces greenhouse gas emissions. WTE also allows for further metals recovery from ash prior to disposal.[14]

Landfilling. Even with effective waste reduction, recycling and WTE programs, there will always exist some waste that cannot be further reclaimed and that requires disposal. The final resting place will be a landfill for the vast majority of this type of waste.

Sanitary landfills are the primary SWD option in the United States and other developed countries. Although less prevalent in developing countries, the use of sanitary landfills is growing in importance in many developing countries — for example, in Latin American countries. Sanitary landfills are designed and engineered to contain waste until it is stabilized biologically, chemically and physically, thereby reducing pollutant releases to the environment (Figure 1-6).

[14] Frankiewicz, T., C. Leatherwood, and B. Dieleman. 2011. *Landfill Gas Energy: An Important Component of Integrated Solid Waste Management*. LMOP LFG 34 Paper. http://www.scsengineers.com/Papers/Leatherwood_Dieleman_(2011)_LFGE-Important_Component_of_Integrated_SWM.pdf.

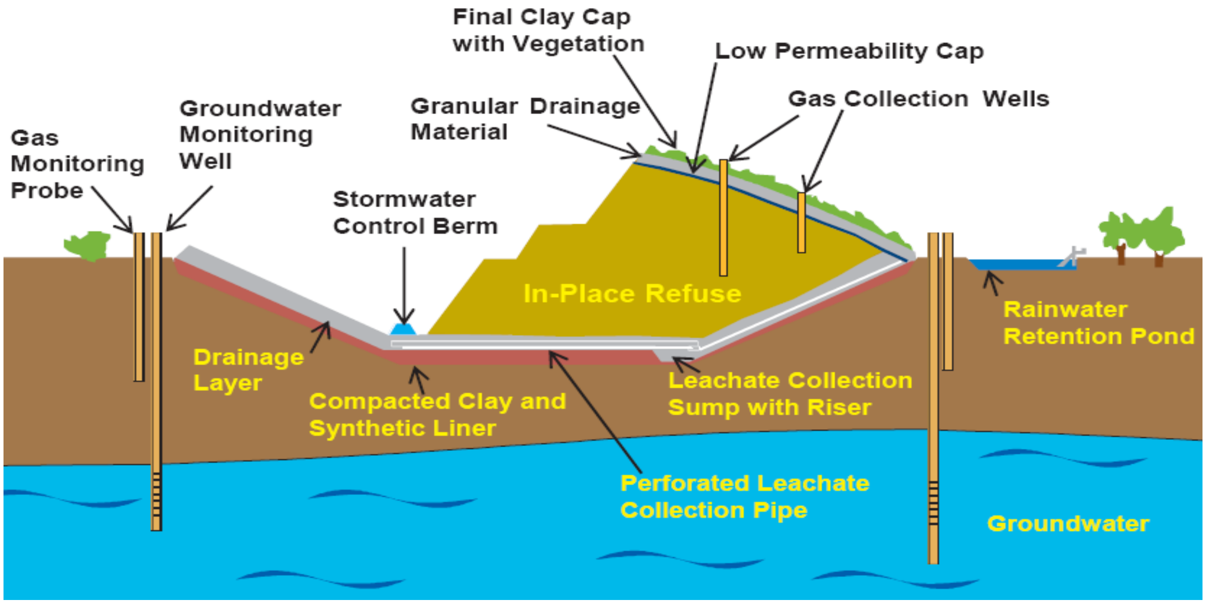


Figure 1-6. Modern Sanitary Landfill

Figure 1-7. Waste Pickers at a Landfill in Jilin City, China

Conversely, uncontrolled dumps, which are currently employed as the primary SWD method in most developing countries, are generally mediocre or even poor in terms of environmental performance. Uncontrolled dump sites can pose major public health concerns through emissions of air pollutants (such as non-methane organic compounds), and leaching of waste constituents can pollute ground water and surface water, contaminating drinking water supplies and aquatic food sources. Scavenging birds and animals can also spread disease. Human scavenging of open dumps, in addition to exposing people to hazardous and toxic chemicals and potential disease vectors, also exposes them to physical injury (see Figure 1-7).

Where possible, phasing out and upgrading uncontrolled and controlled dumps to sanitary landfills are necessary first steps toward sustainable SWD practices. Making small incremental improvements in design and operations over an extended period of time may be more successful than attempting to incorporate all of the necessary changes at once. For example, applying daily cover material could be a first step to reduce the immediate health and disease threats posed by uncontrolled dumps. Installing liners and leachate control systems are more labor- and cost-intensive steps that require careful planning and design, but are usually necessary in the long term to provide adequate ground and surface water protection.[15]

[15] U.S. EPA. 2011. *RCRA Orientation Manual 2011: Resource Conservation and Recovery Act*. http://www.epa.gov/wastes/inforesources/pubs/orientat/.

Manual sanitary landfills are a technical and economically feasible alternative for smaller urban and rural communities that do not have the means to acquire the equipment to construct and operate a conventional sanitary landfill. The construction of a manual sanitary landfill can be done without heavy machinery and is adequate for towns that produce up to 15 tons of waste per day. Local conditions should be considered to ensure that a manual sanitary landfill is the most appropriate option.[16]

Social Impacts of LFGE Project Development

In many developing countries, people who live in and around landfills and open dump sites collect and sell recyclable items for income. When LFGE projects are developed, it is important to consider how the conversion of landfills and dump sites to LFGE facilities affects the livelihood of these individuals.

Anaerobic conditions are created when waste is piled deeply, compacted or covered in certain uncontrolled or managed dumps and sanitary landfills. Under these conditions, bacteria decompose the organic content of waste over time, generating LFG (primarily methane and carbon dioxide). Left uncollected, LFG can escape to the atmosphere, build up in pockets within the landfill, or migrate underground. Landfill methane emissions are the largest source of global GHG emissions from the waste sector. Uncontrolled LFG emissions can create environmental, public health and safety issues from the release of toxic air constituents and odors and contribute to fires or explosions (landfill fires or explosions in nearby homes and building into which methane-containing LFG has migrated). The potential of gas to migrate can be minimized by venting the gas to the atmosphere, which poses additional public health and environmental concerns from release of air toxics. Recovering LFG for combustion by a flare or for productive use as energy are the preferred methods for controlling emissions by destroying methane and other non-methane organic constituents.

Role of ISWM in Developing Sustainable Waste Management Practices

While a generally agreed upon ISWM hierarchy exists, the selection of management methods should be based on the needs and means of the local government, as well as environmental regulations and national, regional and local policies, and the availability of markets for compost, recyclables and electricity. Each community must decide which waste management method is best based on its unique environmental needs, economic situation and public policies. Additionally, no single process or technology can handle all of a community's waste; therefore, a number of integrated methods for effective waste management should be considered. Initiatives from one jurisdiction cannot always be exported to another and be expected to work as the local volume and composition of waste, infrastructure, economic resources, climate and cultural traditions and norms can vary significantly. In addition, economic considerations must be evaluated to identify the most appropriate solutions. For example, constructing a plasma gasification project in a small rural community of 25,000 inhabitants may prove uneconomical as a result of the higher capital costs associated with the technology. The key to effective ISWM is the design and development of waste management systems that best fit local needs

Example: Considerations for High Levels of Wet Organic Waste

Constructing a waste-to-energy plant in a developing country with high levels of wet organic waste such as food waste may cause operational challenges and increase costs because many WTE technologies are designed to burn wastes that are lower in wet food wastes and higher in readily combustible materials such as paper and plastics. This consideration is one of many to ensure effective waste management.

[16] Jaramillo, Jorge. 2003. *Guidelines for the Design, Construction and Operation of Manual Sanitary Landfills.* http://whqlibdoc.who.int/paho/2003/a85640.pdf.

and challenges. Developing countries are beginning to recognize the need for a comprehensive approach to undertake sustainable waste management practices. For example, in Argentina, the federal government has embarked on a national ISWM strategy that includes closure of uncontrolled dump sites in favor of regional modern sanitary landfills to serve populations from local communities and businesses.

Role of Landfill Gas Recovery and Use

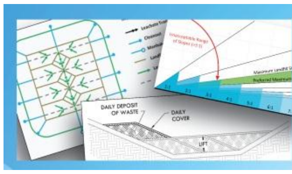
Recovery of LFG is a critical component of ISWM. LFG recovery for flaring or for productive use as an energy source is an effective method to reduce uncontrolled air emissions and improve public health and safety and the environment. With multiple environmental, social, and economic benefits, LFG recovery plays a critical role in municipal solid waste (MSW) management. LFG energy is a small but important component of an integrated approach to solid waste management given that the use of landfills continues to remain the predominant method of SWD in most countries.

> **Environmental, Social and Economic Benefits of LFG Recovery and Use**
>
> Collecting LFG for flaring, direct use or electricity generation provides environmental, social and economic benefits:
>
> - Reduces greenhouse gas emissions
> - Improves energy independence
> - Produces cost savings
> - Creates jobs
> - Helps local economies

The use of LFG depends on establishing a policy and institutional framework to support and promote LFGE projects. The U.S. EPA waste hierarchy[17] treats landfills and WTE equally, as environmentally acceptable SWD options. However, source reduction, recycling and composting are the more environmentally preferred waste management options. When these preferred methods of waste management are not employed and use of landfills is the available option, energy recovery improves the GHG profile and makes use of the energy generated as the organic fraction of MSW decomposes. Where landfills exist, the use of methane generated by the decomposing waste already in place to produce energy is the best-case option to reduce GHG emissions and provide an alternative to fossil fuel-based power generation. Many landfills in developed countries already collect LFG and either use it to power engines for electricity generation, transmit it in a pipeline to a nearby end user to replace fossil fuel use (such as a boiler, kiln and dryer), or flare it. Internationally, significant opportunities exist for expanding LFG energy, which will be discussed in later sections of this guide.

> **Best Practices for ISWM and LFGE Projects**
>
> Incorporating ISWM and LFGE best practices can help to protect human health and the environment from the dangers of improperly managed and disposed waste. Finding the proper mix of practices to meet a local community's means and needs will help ensure a healthier population and environment.

[17] Frankiewicz, T., C. Leatherwood, and B. Dieleman. 2011. *Landfill Gas Energy: An Important Component of Integrated Solid Waste Management*. LMOP LFG 34 Paper. http://www.scsengineers.com/Papers/Leatherwood_Dieleman_(2011)_LFGE-Important_Component_of_Integrated_SWM.pdf.



CHAPTER 2

Solid Waste Disposal Site Design and Operational Considerations

This chapter presents the best practices in SWD site design and operations to improve LFG collection. These best practices are the result of experience in striving to collect LFG efficiently, either as a safety measure or to comply with regulations. This chapter discusses the components of an SWD site necessary to collect LFG and how the lack or inadequate employment of these components will affect the generation of LFG, the methane content, and the collection efficiency of the LFG collection system. A description is provided of the basic technologies employed and the more advanced options for each of the components mentioned in the chapter. At the end of the chapter, a table summarizes the effects of the existence, or lack, of any of the SWD site components mentioned in this chapter on LFG generation and collection.

Worldwide, SWD sites are still the most common method to dispose of municipal solid waste. The types of SWD sites used vary greatly from developed to developing countries and from urban to rural settings. SWD sites can be categorized into three groups, depending on the main characteristics of the sites: open dump, controlled landfill/dump, and sanitary landfill.[1]

Landfill Operational Guidelines

The International Solid Waste Association's (ISWA) *Landfill Operational Guidelines (2nd Edition)* provides additional design and operation details about landfills that are not covered in this guide.

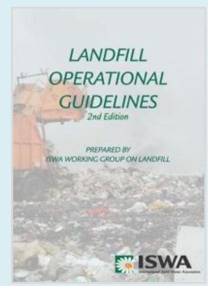


Table 2-1 compares the basic differences between the three types of SWD sites and the negative environmental and health impacts associated with each type. A direct relationship exists between the type and condition of an SWD site and the amount of LFG that could be collected from the site. For this reason, distinguishing among the different types of commonly used SWD sites is important.

Table 2-1. Comparisons of Solid Waste Disposal Sites

Factor	Open Dump	Controlled Landfill/Dump	Sanitary Landfill
Environmental Factors			
Atmosphere			
Fires	Intentional burning common	Limited, may be present	Unlikely
Release of hazardous gases	Yes, if no collection exists	Yes, if no collection exists	Yes, if no collection exists
LFG collection and control	Possible, poor collection efficiency expected	Likely, collection efficiency will depend on site conditions	Likely
Unpleasant odors	Yes	Possible, depending on site conditions and whether LFG is controlled	Minimal, if the right measures are taken to cover waste and control LFG
Ground/Soil			
Topographical Modification	Yes	Yes	Yes
Contamination (leachate)	Yes	Possible, depending on base or liner conditions	No
Gas Migration	Yes	Possible, depending on site conditions	No

[1] International Energy Agency. 2009. *Turning a Liability into an Asset: the Importance of Policy in Fostering Landfill Gas Use Worldwide*. http://www.iea.org/papers/2009/landfill.pdf.

Factor	Open Dump	Controlled Landfill/Dump	Sanitary Landfill
Water (surface and ground water)			
Channeling runoff	No	Possible, depending on site conditions	Yes
Contamination	Likely underground and surface water	Possible if low-permeability liners are not used	Minimal
Monitoring system present	No	No	Yes
Flora			
Vegetative cover alteration	Yes	Yes	Yes
Fauna			
Changes in diversity	Likely	Yes	No
Vector control	No	Potentially, depending on site conditions	No
Socioeconomic Factors			
Landscape			
Alteration of Condition	Yes	Yes, can be mitigated with visual buffer (for example, a forest buffer)	Yes, can be mitigated with visual buffer (for example, a forest buffer)
Humans			
Health hazards	Yes	Potentially, depending on site conditions	Potentially, depending on site conditions
Negative image	Yes	Yes	Yes, improved if there is post-closure utilization of land
Environmental education	No	Yes, in some cases	Yes, with careful planning
Economics			
Decline of land value	Yes	Yes	Yes
Formal employment	No	Yes	Yes
Changes in land use	Yes	Yes	Yes
Social			
Waste pickers	Yes	Yes, in some cases	No

2.1 Sanitary Landfill Design

The objective of sanitary landfill design is to provide for safe disposal of waste while protecting human health and the environment. Sanitary landfills should be designed and managed to protect soil, ground water, surface water and air. Other important objectives of sanitary landfill design are to maximize the waste disposal quantity in the available space given site conditions, geometry, consideration of slope stability and future potential uses. Additionally, a well-designed and operated sanitary landfill will provide cost savings over the life of the site as preventive measures are often less costly than mitigation efforts associated with poorly designed and operated SWD sites.

Sanitary landfill design is a science that is continuously evolving as new technologies and practices arise. As new technologies are tested and proven, they become the recommended standard for use, and in some cases, are adopted within solid waste regulations. Prescriptive standards stipulate the materials, design and construction methods to use in the development of a sanitary landfill. In contrast, performance-based standards state the goals and objectives to be achieved and allow the user flexibility in choosing materials, design and construction methods to meet the stated goals and objectives.

Effective landfill design must be a fully integrated system that is led from the regulators and those responsible for the review and project implementation of design standards. In many solid waste regulations, governments have chosen the prescriptive approach, requiring the use of certain technologies in the construction of a sanitary landfill, such as in the United States, Australia and Germany. However, in some cases and or under special circumstances, the use of other types of technologies is permitted as long as they have been demonstrated to provide equivalent protection of the environment. Some governments have taken this latter approach in their solid waste regulations, allowing just the use of performance-based SWD site standards in light of the flexibility they provide for design and construction. This flexibility is especially important in circumstances where a basic technology is more appropriate.

✔ Example: SWD Site Design Regulations

In the United States, all municipal solid waste landfills must comply with federal regulations 40 Code of Federal Regulations (CFR) Part 258 (RCRA Subtitle D) which establishes criteria for municipal solid waste landfills.[2]

✔ Example: SWD Site Design Guidance

In Brazil, no regulation exists for SWD site design, but the Brazilian Institute of Municipal Management (IBAM) published a manual on Integrated Solid Waste Management (ISWM) that contains guidance on SWD site design. Implementation of the recommendations in the manual is sometimes seen in Brazilian SWD sites.

Regulations regarding SWD site design, either by prescribing specific standards or by enumerating performance standards, are common in developed countries. However, no regulations exist for the design or operation of SWD sites in many developing countries. A general solid waste management law might mention the need for SWD sites to have a bottom liner, leachate management, final cover and LFG venting. In some countries, SWD site design and operations manuals are published by professional engineering associations or other entities, and recommendations in the manuals are commonly practiced in the country. The adoption of standards from other, more developed, countries is common in other countries that do not have SWD site design regulations or engineering association standards. The next few sections will cover the important components of a SWD site design, including bottom liner systems, leachate collection and management systems, grading and re-grading, and final capping systems.

Bottom Liner Systems

The objective of the bottom liner is to protect the soil and ground water from the pollution that originates within the waste mass. The bottom liner creates an impermeable barrier between the waste mass and underlying soils and ground water and is applied to the entire surface of the landfill to prevent both horizontal and vertical migration. Liners also serve as a barrier to LFG migration to surrounding soils. LFG seeks the path of least resistance, so as it encounters the barrier it will seek other pathways to exit the waste mass.

Bottom liner systems range from a simple single liner to composite liners. The use of a particular bottom liner system will depend on the conditions of the site, climate, SWD site size, cost, and any applicable construction regulations pertaining to the region or country where the site is located. Defining the appropriate liner system based on the physical setting of the site allows site-specific conditions to be considered and would provide efficiency in the design and installation of liners. For example, sites with high permeable *in situ* soils and high ground water levels would require a more protective liner system with low-permeable clay and a geomembrane. Sites in dryer climates with deep ground water levels

[2] Electronic Code of Federal Regulations, Title 40, Part 258 (Criteria for Municipal Solid Waste Landfills). http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title40/40cfr258_main_02.tpl.

would not require as stringent a liner system to protect the ground water, but a minimum low-permeable liner system is recommended to provide the necessary barrier for gas migration.

The bottom liner system can be composed of one or a combination of the following:

- Low-permeability clay compacted to achieve a specified minimum permeability. The general recommendation is for the clay to strive for the permeability to be less than 10^{-6} centimeter(cm)/sec[3]. This is usually achieved by using a 60-cm-thick layer of clay, compacted in 15-cm lifts.
- Different types of geosynthetic components including: geonets, geotextiles or geomembranes.

Descriptions of the different materials used in liners and information on the different types of bottom liner systems can be found in various reference materials, including *Solid Waste Landfill Engineering and Design* by McBean et al. and the Landfill Types and Liner Systems Fact Sheet produced by Ohio State University.[4] Several factors can influence the cost of the liner system. For example, the proximity of a source of clay soils and the cost for transporting them to the site can result in a large variance in the cost of a clay liner system. Additionally, the cost for shipping geomembrane from out of country or long distance also can result in large cost variances.

Documenting the bottom liner elevations with an as-built survey (to obtain horizontal and vertical dimensional data) is imperative. The bottom liner elevations are required to calculate the volume of the waste mass. In addition, accurate bottom liner elevations are critical when vertical LFG extraction wells are installed to avoid drilling through the liner systems.

Leachate Collection and Management Systems

Design Specifications and Objectives. Leachate is a wastewater formed when water percolates through or comes in contact with the waste mass. Leachate contains high concentrations of organic and inorganic constituents that can be toxic. Leachate can contain both dissolved chemicals such as chloride, sodium, iron and aluminum and suspended materials such as chemical precipitates, waste materials and bacteria colonies. In an SWD site, leachate can originate from two sources: moisture contained in the solid waste when it is disposed of, and external sources of water such as rain. At sites where rain is the principal source of leachate formation, extensive control via stormwater management is crucial for minimizing the creation of leachate in the first place. The better the stormwater management, the more control an SWD site owner has with leachate management. Effective stormwater management is especially important in tropical regions that experience large amounts of rain.

The major concerns of leachate have to do with its migration to and contamination of surface and ground water and its impediment to LFG collection when it accumulates and floods LFG collection wells. Control of leachate migration starts by properly siting, designing, constructing and operating the SWD site. A Leachate Collection and Removal System (LCRS) is designed to collect, conduct and store the leachate for its treatment on site or off site.

Excessive amounts of leachate can hinder the efficient collection of LFG because the leachate can build up and prevent movement of LFG to the well. Therefore, installation of an adequate leachate collection and removal system is instrumental to extract the leachate out of the waste mass and ensure the efficient operation of the LFG collection and control system.

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[3] California Integrated Waste Management Board. *Landfill Facility Compliance Study Task 6 Report - Review of MSW Landfill Regulations from Selected States and Countries.* 2004.

[4] McBean, E., Rover, F. and Farquhar, G. *Solid Waste Landfill Engineering and Design*. Englewood Cliffs: Prentice, 1995.

An LCRS normally consists of a drainage layer above the liner system. This drainage layer provides a means for the leachate to flow above the liner system. Typically, a network of pipes is installed within the drainage layer to transport leachate to a collection point (such as a lagoon or storage tank).[5] A typical layout of an LCRS can be seen in Figure 2-1. Note the bottom slope direction in Figure 2-1. The bottom of the SWD site needs to be gently sloped to promote leachate drainage to the cleanout lines (see Figure 2-2).

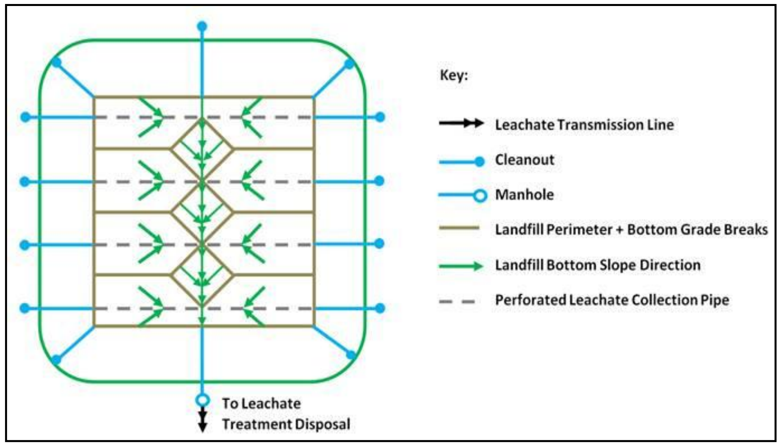

Figure 2-1. Typical Layout of Leachate Collection System (top view)

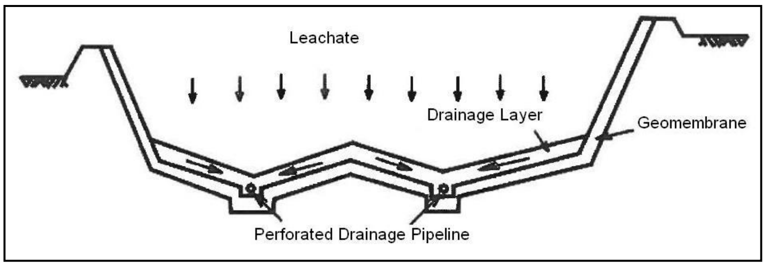

Figure 2-2. Side View of Leachate Drainage Slopes

In some developing countries, the leachate transportation conduits are sometimes combined with LFG vent wells. The leachate extraction system at many of these sites drains the leachate using gravity; however, low permeability of organic material makes gravity less effective for moving leachate. Leachate pumps can improve circulation at some sites. In the gravity systems, if the LFG vent wells are not emanating LFG because of positive pressure within the waste mass, then possible air intrusion into the waste mass can occur and result in semi-aerobic conditions. A semi-aerobic waste mass generates less LFG because activity of methanogenic bacteria is suppressed. If an active LFG extraction system is attached to vent wells that are also used for leachate management, then care should be taken to avoid air intrusion into the waste mass.

Once the leachate has been collected from the SWD site, there are several options to properly manage disposal. These options include on-site treatment (for example, aeration or reverse osmosis) and disposal to a wastewater treatment plant or discharge to surface water, transport to a wastewater treatment plant, evaporation (see Chapter 4), and recirculation (see below).

Leachate Recirculation. Some SWD sites choose to recirculate leachate as a management strategy. Leachate is re-circulated through the waste mass using surface or subsurface methods. The recirculation of leachate increases the moisture content of the waste mass, which increases the generation rate of LFG. However, leachate recirculation systems should be considered only at well-managed, stable SWD sites and must be managed diligently to avoid leachate breakouts and slope stability concerns.

World Bank's Handbook

The World Bank's Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean discusses the advantages and disadvantages of using leachate recirculation approaches and major considerations.

[5] Hickman, H. Jr. *Principles of Integrated Solid Waste Management*. American Academy of Environmental Engineers. 1999.

Grading and Re-grading SWD Site Slopes

SWD site slopes should be maintained to be no steeper than a 3:1 (3 horizontal to 1 vertical) grade. Steep side slopes can cause instability, leading to side slope failure, erosion and loss of the soil cover. Loss of the soil cover and the eventual side erosion can lead to breakouts of leachate and LFG, as well as air infiltration into the waste mass. The intrusion of air into the waste mass can lead to underground fires. If the SWD site has an LFG collection system, side slope air infiltration also can reach the system and dilute and lower the quality of the LFG. Figure 2-3 provides an example of slope recommendations for SWD sites.

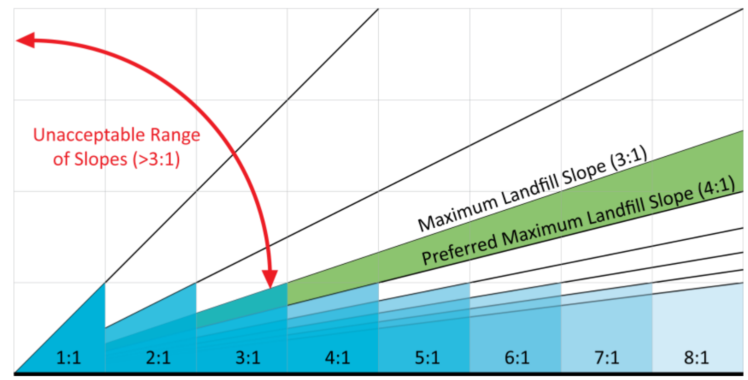

Figure 2-3. SWD Site Slope Recommendations

Side slopes should be designed to be considerably less steep, such as slopes with a grade of 5:1, in seismically active areas or in areas with poor soils.[6] A geotechnical evaluation, or slope stability analysis, will help establish the safest side slope grade. When slope angles are designed, final land use should be taken into consideration. For example, sites that may be restored to agriculture should use more shallow slope angles (10:1 to 15:1) to help with erosion control. Re-grading SWD sites with steep side slopes may be required to mitigate the problems outlined above.[7]

Final Capping Systems

The objectives of the final capping system are to: (1) minimize infiltration of precipitation into the waste mass, thus reducing leachate generation, (2) minimize air intrusion into the waste mass, (3) promote good surface water drainage, and (4) control LFG emissions. For efficient LFG collection, final covers minimize the creation of leachate and minimize fugitive emissions of LFG, allowing for improvement of LFG collection. However, in SWD sites that do not have impermeable bottom liners, a final cap will block the emissions of LFG to the atmosphere and promote its migration to the soils around and under the waste mass (methane migration). Methane migration is a safety concern and should be minimized. Installation of an active LFG collection and control system is an effective method for minimizing methane migration

Final capping systems can include different components such as a buffer layer at the waste interface, gas channels, infiltration prevention (composite liners), cover soils, erosion layer (topsoil) and vegetative cover.

For LFG collection, the most important factor of the final capping system is its permeability. Permeability affects LFG management and system performance. Low-permeability covers minimize LFG venting to the atmosphere, air intrusion, and moisture infiltration into the waste mass; they also can help improve the performance of extraction wells. The type of capping system will also need to be considered in designing an LFG collection system, as the final design of a capping system can alter LFG collection characteristics.

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[6] Ibid.

[7] Datta, M., and Vittal, P. 2010. *Stability of Cover Systems for Landfills and Old Waste Dumps*. Presented at the International Conference on Sustainability Solid Waste Management, Chennai, India, 5-7 September, 2010. http://www.swlf.ait.ac.th/IntlConf/Data/ICSSWM%20web/FullPaper/Session%20VI%20A/6_A3%20_Dr.Manoj%20Datta_.pdf.

For example, proper sealing of any penetrations into a synthetic cap should be conducted to maximize LFG collection and minimize oxygen infiltration.

Additionally, the final capping system must include stormwater controls to transport stormwater and prevent erosion of the final cover. One of the most common and essential types of stormwater controls are benches. Benches are terraces along the final side slopes of the SWD site to provide a means of breaking the downward movement of the stormwater and reduce its velocity. Benches included every 4 to 10 meters of vertical height support stormwater management and slope stability. The top of the SWD site also should be graded to promote stormwater runoff (dome shape). Finally, the recommended final side slopes of a SWD site should not be steeper than 3:1.

2.2 SWD Site Operations

Best practices for SWD site operations are discussed in this section.

Filling Operations/Fill Sequence Plan

The waste filling sequence in a SWD site has an impact on the generation and collection of LFG. The filling sequence affects the stormwater management, LFG collection and soil management systems. Implementing a fill sequence plan can promote efficient operation (especially during wet weather), aid in optimizing filling operations, planning access roads and drainage systems and establishing and implementing long-term SWD site objectives. Fill sequence plans should be based on projected waste disposal forecasts and allow for efficient installation of the LFG collection system as cells or lifts are completed.

Working Face Operations

Daily operations have an important influence on the potential collection of LFG. The area where the waste is being deposited, spread and compacted is known as the working face. It should be maintained to be narrow enough so the waste can be compacted and covered rapidly, minimizing water infiltration, blowing litter, rodents and odors. The working face also should be gently sloped through bulldozer and compactor operations to inhibit stormwater flow into the waste, thus minimizing leachate formation. Other considerations such as cover material, fire control and customer needs should be taken into account when the width of the working face is sized.

A lift is a series of adjoining working faces that are all the same height. Lift heights are normally maintained in the 2- to 5-meter range because these heights will not cause severe settlement and slope stability problems and also facilitate efficient waste compaction. Figure 2-4 provides an example of a solid waste lift. The final design elevation is reached as lifts are added, one lift upon another. SWD site depths of more than 10 meters are recommended for faster LFG generation because a deeper waste mass promotes anaerobic conditions. A deeper waste mass also allows for LFG collection via fewer wells (see Chapter 3).

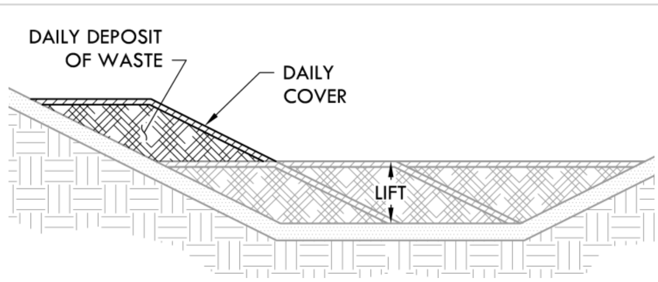


Figure 2-4. Example of a Solid Waste Lift

If LFG wells are installed at active SWD sites, care must be taken to protect the LFG collection pipes to avoid air intrusion and damage from heavy equipment. The ISWA Field Procedures Handbook for the Operation of Landfill Biogas Systems provides further details on operational considerations.

Waste Compaction

The density of the waste achieved by waste compaction has an effect on the potential LFG quantity that can be generated over time. Given that SWD sites are typically designed based on volume, increased waste density allows for more waste to be placed in a given volume. Therefore, the more waste mass disposed of in an SWD site, the more LFG that can be generated. Waste compaction also increases the anaerobic conditions necessary for LFG generation because it reduces the air pockets within the waste mass. The overall economics of an SWD site is improved through increased waste compaction in that more waste can be deposited in a fixed volume. Increased waste compaction also affords a SWD site owner other benefits such as limited permeability of the waste mass, minimized differential settlement as the waste biodegrades and reduced cover soil required relative to the amount of waste disposed of. In addition, increased waste compaction limits the spread of fires.

Daily/Intermediate Cover

Daily cover refers to the material applied to cover the working face at the end of the day. The main purposes of daily cover are to reduce stormwater infiltration, limit stormwater runoff, control odors and rodents, and help prevent fires. Daily cover is also an important management practice that aids in the production and more efficient collection of LFG. Application of daily cover seals the waste components off from the outside environment – a primary condition for facilitating the anaerobic decomposition of waste. The cover material also serves as a barrier to limit the amount of LFG that escapes to the atmosphere.

Several types of materials can be used as daily cover. In many cases, the materials will depend on what is available to the SWD site and the cost. The typical cover material is soil; however, there are other materials commonly used such as clay, sand and alternative daily covers (for example, tarps, foundry sand and contaminated soils). The use of other materials might depend on their availability and cost. The general recommendation is to spread the material as an even layer of 15 cm over the waste at the end of the working day and to remove as much as possible of the layer the next day. Removal of daily cover is important for prolonging the life of the site by limiting the amount of soil retained in the landfill volume.

The permeability of the daily cover material will affect LFG production. More permeable materials, like sand, will allow higher rates of moisture infiltration, leading to wetter waste and an increased rate of LFG production. The use of less-permeable materials, such as clay, will reduce moisture and air infiltration into the waste mass. However, if the less permeable cover is not removed the next day, it will create layered conditions inside the landfill that can allow leachate to accumulate and impede the movement of LFG toward the collection system. This condition may cause the leachate to submerge the extraction wells and may also lead to leachate seeping out of the side slope of the SWD site.

Intermediate covers are to be used in areas that will not receive waste for an extended period of time (such as 1 year), providing the same general functions as daily cover. Intermediate covers are typically less than 1 meter thick and are to be removed as much as possible once operations in the inactive area are restarted. Removing the intermediate cover will recover available airspace and reduce the number of suspended zones and ponding that could occur on top of each intermediate layer if a less-permeable cover material was used.

Leachate Management

An effective leachate management system is important for proper SWD site operations. If the leachate system does not function, leachate will build up in the waste mass, leading to slope instability and disruption of the operation of the LFG gas collection system. Proper precautions when the leachate management system is designed and the extraction system maintained, whether manual or automatic, are essential to avoid clogging the system. Blockage of the leachate system is caused by one (or more) of the following factors: sedimentation, biological growth and pipe breakage or deterioration. Another important consideration is to design the proper size for the leachate storage and treatment facility, as sizing ensures that additional and unforeseen amounts of leachate can be effectively accommodated.

Fires

Waste fires pose serious risks and some can be difficult to extinguish. While fires at well-operated SWD sites seldom happen, they frequently can be found at unmanaged or poorly managed dump sites. Prevention of fires is an extremely important task of SWD site operations, not only for the serious damage fires can cause to the infrastructure and slopes, but also to health, safety and the environment. Fires can affect the potential for LFG collection by either destroying the LFG collection system or by combusting the organic waste materials that would ultimately produce LFG.

The two types of fires at SWD sites include surface and sub-surface fires. Surface fires can be caused from loads that arrived to the site already smoldering, on fire, or contain materials that can easily ignite. Surface fires also can be started by the equipment operating on the SWD site or from smoking on the site. In open dumps, scavengers may start fires to find valuable materials to recycle such as metal. To avoid surface fires, the operator should observe all loads as they are being deposited on the working face, designate smoking areas away from SWD operations, and keep a fire extinguisher in all equipment.

Sub-surface fires can take place close to the surface or deep-seated within the waste mass. Sub-surface fires require a significant amount of resources to extinguish. Most sub-surface fires are the result of air infiltration into the waste mass; however, they are principally the result of the interaction of the three elements needed for any fire: fuel, oxygen and heat. Most waste materials in the waste mass are combustible and, along with LFG, represent the fuel supply. The heat can be created by microbial activity or spontaneous chemical reactions inside the waste mass. Oxygen can infiltrate when wastes are being deposited or can be directly drawn in through the surface.

Fire Prevention

As a general preventive measure to deal with any type of fire, the SWD site should implement a fire prevention and extinguishment program. ISWA describes a categorization of SWD site fires given levels of alert and offers recommendations on the first actions, methods of extinguishment and prevention of such fires.[8]

Several methods of identifying sub-surface fires exist and range from changes in the physical aspect of the waste mass (appearance of smoke, subsidence, fissures and venting holes) to monitoring the internal temperature of the waste mass and carbon monoxide concentrations in the LFG. To avoid sub-surface fires, the recommendation is to limit all air and oxygen intrusion, monitor the site conditions regularly, and maintain all cover on closed portions of the site. If the SWD site has an LFG collection system, keeping the system balanced and monitoring well temperatures and gas composition are important. (See Chapter 3 for more information on balancing and maintaining the LFG collection and control system.)

2.3 SWD Site Conditions and Their Effects on LFG Project Development

Many of the conditions of SWD sites in developing countries resemble poorly operated landfills or open dumps. These conditions, if not modified, will hinder the development of a successful LFG project. The minimum SWD site design and operation conditions necessary for optimal LFG collection were discussed

[8] ISWA. January 2010. *Landfill Operational Guidelines*. Second Edition.

earlier in this chapter. As many of these conditions are considered to be of the optimal design and construction of a sanitary landfill, the implementation or upgrade of SWD sites toward these conditions will have the collateral benefits that are provided by proper sanitary landfills, with the additional benefit that LFG can be feasibly collected and utilized. Table 2-2 shows a qualitative assessment of how conditions of many SWD sites in developing countries affect successful LFG project development. The conditions affect several aspects of LFG projects, including the amount of methane in the gas and the percentage of LFG that can be collected. The level of impact (no impact, increases and decreases) of each SWD site condition to each aspect is shown in Table 2-2.

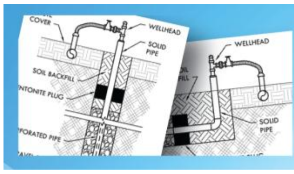
Table 2-2. Conditions that Impact LFG Project Development

Component	As Found Condition	LFG Generation	Amount of Methane in LFG	Collection Efficiency
Bottom Liner	None or Inadequate	No Impact	No Impact	Decreases
	Adequate	No Impact	No Impact	Increases
Leachate Collection and Removal System	None or Inadequate	Decreases	Decreases	Decreases
	Adequate	Increases	Increases	Increases
Final Capping	None or Inadequate	Decreases	Decreases	Decreases
	Adequate	Increases	Increases	Increases
Planned Filling Operations	None or Inadequate	Decreases	Decreases	Decreases
	Adequate	Increases	Increases	Increases
Compaction	None or Inadequate	Decreases	Decreases	Decreases
	Adequate	Increases	Increases	Increases
Daily and or Intermediate Cover	None or Inadequate	Decreases	Decreases	Decreases
	Adequate	Increases	Increases	Increases
Slopes	None or Inadequate	Decreases	Decreases	Decreases
	Adequate	Increases	Increases	Increases
Fire Control	None or Inadequate	Decreases	Decreases	Decreases
	Adequate	Increases	Increases	Increases

Lastly, many of the impacts shown above can be accommodated during the LFG modeling process. These impacts and the modeling parameters that account for them will be discussed in Chapter 6, Landfill Gas Modeling.

Best Practices for SWD Site Design and Operation

Improving the conditions of an SWD site to the standard of a properly designed and operated sanitary landfill will likely improve the collection of LFG. It is important that stakeholders understand how the various components of an SWD site affect the generation of LFG, the methane content, and the collection efficiency of the LFG collection system, including how common flaws in design and overall operation can affect LFG generation. Implementing training opportunities can help to reduce these design and operational flaws. Well-designed and operated sanitary landfills will generate LFG that can be feasibly collected and used and provide cost savings over the life of the project.



CHAPTER 3

Design, Construction and Operation of Landfill Gas Collection and Control Systems

The basis of any LFGE project involves the design, construction and operation of an LFG collection and control system (GCCS). The purpose of a GCCS is to extract LFG from the waste mass and convey it to a combustion device for flaring or energy use. A typical GCCS includes the following primary components: extraction wells; a system of lateral and header (manifold) piping to convey the collected LFG; a condensate management system; a blower and flare system; monitoring devices; and system controls.

This chapter discusses the concepts and considerations for the design, construction and operation of a GCCS. These systems require proper engineering design, construction and operation by trained personnel to operate and meet the needs of an LFG project and maximize intended benefits. In general, maximizing collection efficiency (when the LFG collection rate approaches the LFG generation rate) will improve environmental benefits such as greenhouse gas (GHG) emissions and odor control, while also improving economic return where project revenue depends on LFG collection (such as for energy utilization).

Training Opportunities

Skilled and appropriately trained personnel are needed to operate a GCCS. GMI offers training opportunities on operations of landfills and LFG systems. Visit their website to learn about upcoming training opportunities.

3.1 GCCS Design

Overall GCCS design is based on expected LFG collection, the type and depth of the waste, SWD site conditions and operating status (open or closed), and the overall goals of the LFG project. During the construction phase, use of proper techniques and quality assurance procedures is needed to ensure proper system operation and reliability. Finally, operation of these systems determines the success of the LFG project. Periodic monitoring and adjustments must be made to the GCCS as SWD site conditions constantly change. Changing SWD site conditions are caused by waste filling at open sites, degradation of organic material, settlement of the waste mass and weather conditions. The sections below provide more detail on design, construction and operation of a GCCS.

Extraction Wells

Gas collection begins in the extraction wells, where LFG is extracted from the waste mass and enters the GCCS. Extraction wells are typically composed of slotted plastic pipe, surrounded by stone or other aggregate material, that are installed in borings in the waste mass below the surface of the SWD site. Above the surface of the waste mass, the extraction well typically has a wellhead to allow for vacuum adjustment and sampling of the LFG. The orientation of these wells can either be vertical or horizontal, and the decision to use vertical and or horizontal wells will depend on site-specific factors and goals of the LFG project.

Vertical Wells. Vertical wells are usually installed in areas where the site has stopped receiving waste or where waste filling will not occur for a year or more. However, they can be installed and operated in areas with continued waste placement, but placement will result in increased operation and maintenance requirements. Figure 3-1 provides an example of a vertical extraction well.

The components of a vertical well include the well piping with perforations or slots at the bottom portion of the pipe, clean gravel backfill, soil backfill, a bentonite plug and a wellhead. Polyvinyl chloride

(PVC) piping for vertical well construction is sometimes used, because PVC resists collapsing caused by heat and pressure in deep waste better than high density polyethylene (HDPE) pipes. However, PVC pipe can become brittle over time and crack and collapse. For this reason, HDPE pipe may be preferred and also has been used successfully in vertical wells. A bentonite plug is used to prevent infiltration of air from the surface through the well annulus into the well. Bentonite is a family of clay compounds that expands when wet to serve as an effective seal.[1] The use of a plastic seal around the well at the waste mass interface with the cover soil can also be used to inhibit air infiltration. The amount of vacuum that can be applied to a well (and the overall performance of the GCCS) can be limited by the effectiveness of the seal between the perforated portion of the pipe and the surface of the waste mass and cover soil. The depth of the well depends on the depth of waste and will typically terminate at 3 to 5 meters above the base of the waste mass.

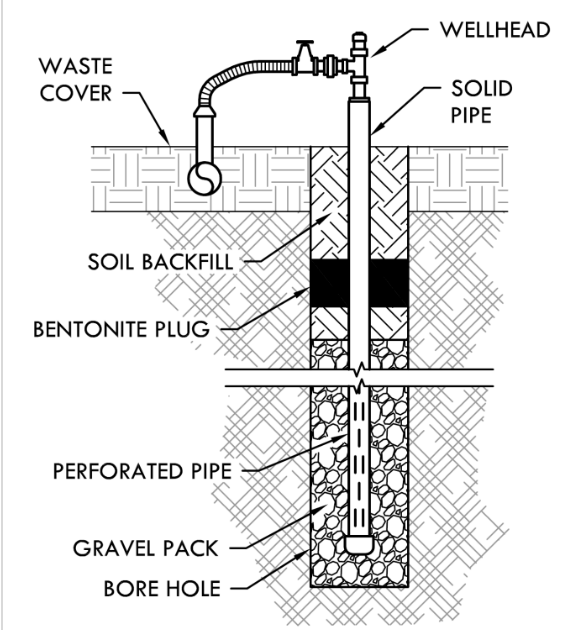


Figure 3-1. Vertical Extraction Well

In some situations, vertical wells can be constructed as the SWD site is filled with waste. In these cases, it is common for concrete or steel piping to be stacked vertically and act as a barrier between the waste and the gravel as the waste is applied around the well. This concrete or steel barrier can be perforated or removed to allow LFG to be extracted from the well at a future date.

Vertical well boreholes range from 20 to 90 cm in diameter and include 5- to 15-cm-diameter pipe. A minimum borehole diameter of 30 cm and pipe diameter of 10 cm are recommended. Larger-diameter boreholes and pipe typically increase LFG collection as a result of the increased surface area. The placement and spacing of vertical wells in a SWD site depend on various site-specific parameters, including:

- Depth of the waste
- Depth of the well
- Leachate levels
- Compaction of the waste
- Type of daily cover (if used)
- Presence of a final cap
- The goals of the LFG project

Horizontal Wells. Horizontal extraction wells can be installed while an SWD site is still receiving waste and may be used if LFG collection is desired in an area before closure. Figure 3-2 provides an example of a horizontal extraction well. Horizontal extraction wells are placed in a trench within the refuse. The trench is backfilled with gravel (or other aggregate such as tire chips or broken glass), and the perforated pipe is installed in the center of the trench. A geotextile fabric is recommended on the top of

[1] U.S. EPA, Office of Solid Waste and Emergency Response (5306W). EPA 530-F-97-002. 7/97. Geosythetic Liners Used in MSW Landfills.

the trench to reduce clogging of the aggregate by the backfill or trash above. Common spacing of horizontal wells is 30 to 40 meters apart. The perforated pipe within the trench is typically 10 to 20 cm in diameter.

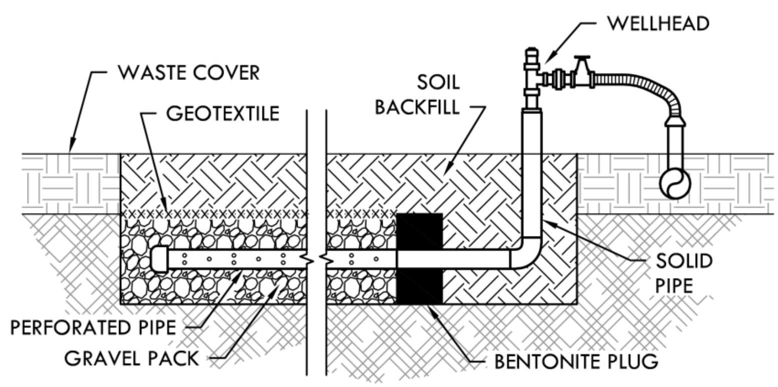


Figure 3-2. Horizontal Extraction Well

The overall goals of the LFG project also should be considered when the placement of extraction wells is planned. For the case of meeting regulatory requirements or significant environmental mitigation issues, a GCCS designer may include additional components to achieve greater emissions control (as an example) even though these collectors may not be cost effective for energy use purposes. However, if an LFG project is being implemented for economic reasons, such as a GHG emission reduction project or for energy use, the extent of well coverage on the SWD site may be prioritized based on economic considerations.

✔ Example: Consider Costs When Placing Extraction Wells

Shallow wells will collect less LFG on a per-well basis than deeper wells and will require denser spacing to achieve comprehensive LFG collection in shallow areas of waste mass. As a result, there may be increased capital and operating costs for smaller levels of LFG collection. Therefore, if economics are a primary consideration, a GCCS designer may choose not to install some shallower wells to minimize costs.

Landfill operations and the overall goals for the GCCS will determine whether vertical or horizontal wells, or both, will be used. Table 3-1 summarizes some general advantages and disadvantages of vertical and horizontal wells, setting aside landfill-specific operations.

Table 3-1. Advantages and Disadvantages of Vertical and Horizontal LFG Collection Wells

Vertical Wells		Horizontal Wells	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Minimal disruption of landfill operations if placed in closed area of landfill Most common design Reliable and accessible for inspection and pumping	Increased operation and maintenance required if installed in active area of landfill Availability of appropriate equipment Delayed gas collection if installed after site or cell closes	Facilitates earlier collection of LFG Reduced need for specialized construction equipment Allows extraction of gas from beneath an active tipping area on a deeper site	Increased likelihood of air intrusion until sufficiently covered with waste More prone to failure because of flooding or landfill settlement

Wellhead Components

Figure 3-3. Wellhead

Wellheads are typically found on the extraction wells above the surface to allow for vacuum adjustment and sampling of the LFG. There are several components of a LFG wellhead: a vacuum control valve; monitoring ports; and an option for flow measurement. The vacuum control valve allows an LFG technician to adjust the vacuum applied at each individual wellhead. The wellhead is often designed with one or two monitoring ports so an LFG technician can measure the temperature, pressure, and composition of the LFG. These ports allow an LFG technician to record the impacts of well adjustments and to identify potential problems and troubleshoot errors that may occur in the GCCS. Frequent wellhead monitoring promotes optimal system operation and allows for effective system maintenance. In addition, wellheads can include a flow measurement device (for example, an orifice plate or pitot tube) to measure the differential pressure of the LFG and use those figures to calculate the LFG flow. The top of the wellhead should include a removable cap to access the well for internal inspection and measure and remove liquids as necessary. High levels of liquid (leachate) in a well can reduce LFG collection, especially if the liquid level is above the perforated pipe section of the well, preventing the gas from moving into the well.

Lateral and Header Piping

Lateral and header piping are installed to transport LFG from the individual wells to the blower and flare system. LFG piping should be designed to accommodate the necessary volume of LFG, minimize vacuum loss and provide consistent vacuum to the individual wells. Lateral pipes connect each well to larger header pipes. Header pipes aggregate the LFG collected and transported in the lateral pipes.

The lateral and header piping system should be designed to accommodate the maximum expected LFG flow rates to minimize future upgrades if LFG collection continues to increase. Pipe sizing should also consider vacuum loss caused by friction and the avoidance of pipe blockage by allowing LFG flow to continue despite moderate condensate build up that results from sagging and in areas where waste can settle.

LFG piping may be installed above the surface or below the surface. Table 3-2 identifies some general advantages and disadvantages for each approach.

Table 3-2. Advantages and Disadvantages of Installing LFG Piping Above or Below Ground Surface

Above Surface		Below Surface	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Reduced system costs in areas where freezing does not occur, interim or final cover has been installed, and scavengers do not have access Increased ability to inspect, repair and upgrade the piping system	Pipes must be protected against weather effects and movement from thermal expansion or contraction, which may result in more frequent cracks and weld separations More difficult maintenance of the waste mass surface or cover (such as grass mowing)	Can result in lower operating costs May be more visually appealing than above-surface piping	More expensive to install

Condensate Management

Condensate refers to the moisture or liquid that is formed when extracted LFG cools. There are many factors that affect the quantity of condensate generated in a GCCS, including the LFG temperature and volume. In addition, the climate conditions at the site also can influence the amount of moisture formed in the LFG. As LFG is collected from the waste mass, it cools and has a reduced ability to hold moisture in a vapor form. The condensation that forms can restrict or completely block the flow of LFG in the piping system. The GCCS must be carefully designed to consider condensate management issues to prevent negative impacts on LFG collection.

The lateral and header systems should be designed to facilitate condensate drainage to low points, where it can be removed from the system by vacuum-sealed sump pumps or allowed to drain back into the waste mass. Typically, a minimum slope of 3 to 5 percent will facilitate condensate drainage even if pipe settlement occurs. If drained back into the waste mass, the condensate low point must include a vacuum trap to prevent air from being drawn into the header. The trap must provide a sufficient vacuum break to match the maximum expected applied vacuum on the system (plus a safety factor).

Once the LFG is collected from the waste mass, it is necessary to treat it to remove moisture and particulates. The removal of moisture and particulates is necessary to reduce the abrasive and corrosive nature of the raw LFG to protect the blower and ensure the LFG will burn effectively in a flare or other combustion device. Particulates are typically removed through the use of filtration. The most common device for moisture control is a moisture separator (sometimes referred to as a knock-out pot), which is a large cylindrical vessel that reduces the velocity of the LFG to allow entrained moisture to fall out of the LFG. A mist eliminator is often used to further remove moisture and other particulates in the LFG. A mist eliminator can be a wire-mesh or plastic-mesh screen through which the LFG passes and collects droplets of water that were too small to be collected by the moisture separator. The wire-mesh screen is subject to potential corrosion. This system also screens out other particulates that the LFG may contain.

Typical condensate management systems will pump the liquids collected by sumps to one or more storage tanks to house the condensate until it can be treated, reused or disposed of. Collected condensate is typically combined with leachate for treatment or disposal.

Blower and Flare Skid

The blower and flare skid is a critical part of the GCCS. The blower provides the vacuum used to collect LFG from the waste mass. It also provides the necessary pressure to push the LFG to the flare or to an energy use device. A flare system is used to combust the LFG and in many cases is required to control odors or mitigate other environmental or health concerns. If possible, the blower and flare system should be centrally located near the LFG collection system or near the energy use device. The flare systems should be installed away from any trees, power lines, or other objects that could be ignited by the flame or damaged by heat.

Once the LFG has been treated, it then flows to the blower where the vacuum at the inlet is adjusted to meet the requirements of the GCCS and the outlet pressure of the gas is adjusted to conform to the requirements of the flare or energy use device. The LFG typically passes through a metering system to measure the flow rate of LFG being collected by the GCCS. Basic metering systems include a volumetric flow meter. However, a continuous methane monitoring system also would be needed to measure the mass flow rate of methane in the LFG. This continuous monitor is especially important if the SWD site is required to collect LFG or is participating in a GHG emission reduction project where the measurement of methane mass flow rate is needed. Energy use projects also may require continuous methane monitoring systems to track the heat content of the LFG (such as in MJ/m^3) and total energy delivery (MJ/month).

Flares

There are generally two types of flares: (1) open flares (candle-stick flares), and (2) enclosed flares (ground flares), as shown in Figure 3-4. Open flares consist of a long vertical pipe, a burner tip and a flame shroud. Open flares that are properly engineered and operated may achieve up to 98 percent destruction efficiency and are usually much smaller than enclosed flares. Open flares can be less costly and easier to install and operate than enclosed flares.

Enclosed flares that are properly engineered and operated may achieve destruction efficiencies of 99 percent or greater. One significant drawback to this type of flare system is that it is more expensive to install and operate than an open flare.

The type and rated capacity of the blower and flare system are determined by anticipated LFG collection rates (see Chapter 6) and the overall goals of the LFG project. SWD sites that are currently accepting waste should anticipate installing a blower and flare system that can process the increased amount of LFG that will be collected as more waste is deposited at the site. Flares are used for all LFG projects, often in combination with an energy utilization project. These flares may run continuously in the case when projects have collected gas quantities in excess of the energy utilization needs or intermittently when used primarily during plant startup or downtime.

Figure 3-4. Open Flare (left) and Enclosed Flare (right)

3.2 GCCS Construction

Once the GCCS is designed (and permitted, if necessary), construction of the system can begin. Construction should employ proven techniques to ensure a well-built system, and a quality assurance program should be implemented to make sure that the system is built in accordance with the required design considerations (such as pipe slopes and well depths). Field engineering decisions will need to be made to account for unforeseen conditions at the time of construction. Construction oversight is important to identify potential changes in the system design needed to accommodate site conditions and to document the as-built condition of the system.

Construction Techniques

Proper construction techniques are important to ensure the successful operation of a GCCS. A separate qualified individual or entity should be identified or hired to provide construction quality assurance (CQA) to monitor and document the techniques used. Typically, the first step in construction of a GCCS is drilling the vertical wells (or installing horizontal wells). It is important not to compromise the containment system when vertical wells are drilled. As the driller gets set to drill each well, the designated CQA monitor should verify the elevation and depth of the well and confirm it matches the construction drawings to avoid drilling through the base (or liner, in some cases) of the SWD site.

Vertical LFG wells typically have a diameter of 20 to 90 cm to easily lift waste materials out and achieve good LFG extraction. A bucket-type auger drill rig is the most desirable type for drilling in solid waste. This type of drill rig uses a large hinged cylindrical bucket with cutting blades at the base to cut through materials. However, this type of drill rig is not commonly available in many countries, and a standard auger also may be used. In addition, some drillers have limited or no experience with solid waste and may not want to use the more expensive bucket-type auger rig in such applications for fear the rigs will be damaged. Figure 3-5 shows a vertical extraction well being drilled with a bucket type auger.

Figure 3-5. Vertical Extraction Well Drilling

When a drilling contractor is selected, it is important to have a clear understanding of the equipment specified for use on the project and for the driller to understand the goals of the drilling process. Inappropriate drilling equipment may result in excessive drilling time. Furthermore, inappropriate equipment may cause unintended short- and or long-term operational issues that may limit LFG collection or allow air to infiltrate into the waste. Once the best available and cost-effective drilling equipment is contracted, the drilling protocol and procedure may need to be adjusted to install effective LFG extraction wells.

It is important that the CQA monitor or the design engineer carefully observe and record the waste conditions encountered at regular intervals for each well when they are drilled. These conditions include moisture content (for example, saturated, wet, moist or dry), presence of leachate, depth of cover soil, waste characteristics and status of waste degradation. This information is important for assessing whether to abandon the well boring and relocate the well and also for tracking the future performance of each well. For example, if the waste materials are saturated with liquids, it may indicate that the well could flood and a pump should be installed in the well to remove the liquids for effective LFG collection. To optimize materials use during installation of the wells, pipes should be cut, slotted, and joined together after each well has been drilled and the exact length of pipe required is known.

Vertical well installation requires planned construction techniques that prioritize the health and safety of workers. Materials excavated from a borehole should be placed upslope so that any liquids draining from the materials flow back into the borehole to minimize exposure to liquids and exposed waste. The borehole should be covered when drilling is not active to minimize the potential of workers falling into the borehole.

Handling Excavated Waste

No holes or trenches should be left uncovered or open overnight. In addition, any waste and soil materials excavated from either a vertical well or trench should be disposed of in the operating section of the SWD site and covered on a daily basis, or appropriately stockpiled for disposal off site. Removal of excavated waste from the drilling area should be a continuous process, such that when the well installation is complete all the excavated waste has been removed and appropriately disposed of or stockpiled.

Horizontal wells are constructed by digging trenches in the surface of an operating area of the SWD site. Trenches are typically excavated to accommodate a 70-cm-wide and 100-cm-deep bed of gravel or aggregate with a pipe centered within. Approximately 15 meters of solid pipe is used at the end of the horizontal well before it reaches an exposed edge of the waste mass to inhibit air intrusion. This length of solid pipe will vary with the site configuration. The solid pipe may also be surrounded by bentonite to prevent air infiltration into the waste mass once a vacuum is applied to the well. After the horizontal well is constructed, waste can continue to be spread over the well. After approximately 4 meters of waste has been placed on top of the horizontal well, vacuum can be applied to the well.

Construction Quality Assurance Procedures

CQA is important for proper installation of a GCCS and for documenting the as-built condition of the system. Preferably, the design engineer should obtain and review available as-built drawings for the bottom liner system or depth of the waste. If as-built drawings are not available, the design engineer should review system construction or permit drawings for the bottom liner. Based on available drawings and the desired location of each well, the depth of waste should be calculated for each well along with a corresponding calculation for the appropriate well depth. These construction drawings should be reviewed by a second qualified engineer to double-check the well locations, waste depths, elevations, and calculations.

Before construction begins, a professional surveyor should stake out each well and collection piping routes. The surveyed elevations and well identification numbers should be recorded (and assigned) and written on stakes positioned at each well location. The recorded survey data should include the horizontal and vertical data for each well stake and collection piping grade stake. In the event one or more of the well location stakes is removed or destroyed, the well locations should be resurveyed before the well location stakes are reestablished. The surveyor should not guess at the location and reestablish the well location stake, which could cause improper or insufficient pipe slopes or a penetration of the bottom liner.

Survey data should be provided to the design engineer for comparison to the existing construction drawings and revised and updated as needed. The revised construction drawings should be submitted to the driller. It is generally good practice to have the design engineer approve the final construction drawings. The CQA monitor should review the construction drawings with the driller, landfill owner, general contractor, and any other appropriate parties to make sure all agree to the drilling plan. It is also good practice for the CQA monitor and contractor to walk the entire SWD site with the driller to identify all well locations and confirm that the drill rig and support equipment are capable of accessing the well locations. It may be necessary to move one or more wells if the proposed well location cannot be made accessible. The CQA monitor should remain on site during the entire construction period.

As the wells and collection piping are being installed, it is important that either the design engineer or the CQA monitor keep accurate records of the pipe depth, pipe location, and the location of special fittings such as tees that mark where a lateral pipe is joined to the header. Other important structures such as condensate traps or condensate sumps should be documented on the as-built drawings to include any deviations from the design plan. As-built drawings should be developed to document the locations of wells, piping, and important structures. The as-built records are important for operations and maintenance of the well field, for future construction efforts, and may be required by regulatory authorities.

3.3 GCCS Operation

General Operating Considerations

Typically, a GCCS operates on a continuous basis. However, SWD site conditions continuously change and the rate of LFG collection will vary temporally and across locations within the waste mass. Changes to SWD site conditions occur for various reasons, such as:

- Air intrusion through cover soil
- Rate of waste disposal and age of the waste
- Changes in atmospheric pressure
- Precipitation and moisture in the waste mass
- Variations in waste characterization.
- Compaction level

These changes require periodic monitoring and adjustment of the vacuum applied to each well to maintain or increase collection efficiency, prevent excessive vacuum application, minimize problems associated with LFG emissions or potential migration, and to optimize energy use project operations. Monitoring can also help detect undesirable subsurface combustion that can result if excessive vacuum is applied to the wellfield (introducing oxygen into the waste mass). Local or national regulations may also affect or prescribe operation and maintenance activities.

Monitoring should be conducted at sufficient frequency to promote optimal system operation and to allow for effective system maintenance. Generally, system monitoring involves examining LFG conditions at the wellheads and the waste mass surface. Typical wellhead monitoring parameters include:

- Volumetric flow rate
- Methane concentration
- Oxygen concentration
- Carbon dioxide concentration
- Balance gas concentration (typically Nitrogen (N_2))
- Temperature
- Vacuum pressure

In addition, measurements of carbon monoxide and hydrogen sulfide provide information about the potential for subsurface fires as well as the corrosive potential of the LFG to subsurface materials.

Start-up Considerations

Start-up of the GCCS can refer to the initial start-up or the return to service from a shutdown. Although general protocols regarding system start-up considerations can be useful, each site should create a site-specific start-up procedure.

During start-up, individual wells are adjusted and balanced to allow the efficient steady-state operation of the system without excessive vacuum application. The system may require further balancing between the wellfield vacuum and pressure at the blower discharge to achieve proper delivery pressure to the flare or energy use device. The LFG blower should be monitored during start-up for unusual noise, temperature, or excessive vibration.

If a flare is used, a pilot flame is ignited before LFG is introduced. The pilot will ensure proper start-up of the flare and maintain flame stability if the LFG flow is less than the minimum required needed for stable operation.

During start-up, a variety of issues must be coordinated to ensure smooth system operation, including wellhead control valve settings; main header valves opened as needed; and proper auxiliary fuel (such as propane) flow to flare. System operators should also monitor for potential gas leaks as the system start-up is initiated. After the flare is lit and stable, LFG pressure should be evaluated and system performance verified.

Routine Operation

Routine operation relies on system monitoring to promote a high LFG collection efficiency, while avoiding excessive vacuums and air intrusion. Wellhead vacuum can indicate that LFG is effectively routed out of the waste mass and into the collection system components. (Note that vacuum can be present without flow if the well is blocked by high liquid level or other obstruction; therefore, flow and velocity measurements are necessary to confirm flow.) Since wellhead vacuum may depend on the relationship with other wells, adjustment of wellhead vacuum requires site-specific knowledge and historical data.

As a general guide, effective system operation can be expected to fall within the following approximate monitored ranges:[2]

- Methane (CH_4): 46 to 55 percent
- Oxygen (O_2): 0 to 0.5 percent
- N_2: 2 to 14 percent
- Carbon Monoxide (CO): less than 25 parts per million by volume
- Wellhead gas temperature: 52 – 60 degrees Celsius (^oC)

Note that SWD sites and collection systems vary and the above ranges may not be successfully or consistently achieved at all project sites. The presence of nitrogen and oxygen in the LFG mixture is the result of air intrusion through the surface of the waste mass or leaks in the system piping. If the latter, the ratio of nitrogen to oxygen will be approximately 4:1, which is characteristic of atmospheric air. If the result of air intrusion, however, the ratio may be greater than the ranges stated above. It is important to recognize this condition, as low oxygen levels do not necessarily indicate a lack of air intrusion. Aerobic bacteria in the cover soils or surface waste layer can consume oxygen as air infiltrates

[2] Solid Waste Association of North America (SWANA). 1997. *Landfill Gas Operation and Maintenance Manual of Practice.* http://www.nrel.gov/docs/legosti/fy97/23070.pdf.

the waste mass and travels toward the extraction well. Therefore, when air intrusion through the waste mass occurs as a result of high vacuum levels, the ratio of nitrogen to oxygen in the resulting LFG mixture at the well can be much greater than 4:1.

The blower should be continuously monitored for unusual noise, temperature or excessive vibration. For sustained operation, the flare must receive LFG flow of sufficient methane content before steady-state operation can be attained. The flare manufacturer will provide the minimum LFG flow needed for steady-state operation. Many times, this is referred to as a “turndown” ratio and most open flares have a 10:1 turndown ratio. As a result, a minimum LFG flow rate of 100 cubic meters per hour (m^3/hr) is required to maintain steady-state operation for a flare rated for 1,000 m^3/hr. Enclosed flares have different configurations that affect the turndown. It is not unusual for an enclosed flare turndown to be only 5:1.

Shutdown Considerations

System shutdowns can be either planned or unplanned. If planned, the shutdown can be used as an opportunity to complete system inspections and maintenance. Planned shutdowns and maintenance can be coordinated to make efficient use of system downtime.

System shutdowns may also be unplanned. Examples of conditions leading to an unplanned shutdown may include the following:

- Insufficient LFG flow to the flare or energy use project. For example, a liquid blockage in the header piping can severely restrict LFG collection.
- Insufficient methane content to the flare or energy use project. For example, a bulldozer may run over a wellhead, causing high oxygen and low methane levels in the collected LFG.
- Blower failure. (System owners often install redundant blower systems to avoid complete system shutdown in the event of blower failure.) For some sites, care should be exercised to ensure that a complete shutdown (not extracting any LFG) does not result in gas migration or odor problems.

Maintenance

GCCS operation depends on effective maintenance, which generally falls into the following categories:

- Planned – Maintenance scheduled at periodic frequencies such as daily, monthly, annual and multi-year as appropriate to prevent system failure, ensure reliability of meters and optimize operation. Documentation of scheduled maintenance is useful in reviewing the maintenance history of equipment and may be helpful in trouble shooting potential problems.
- Routine – Maintenance occurring in the normal course of operation or during regular monitoring efforts.
- Unplanned / Emergency – Not all maintenance is planned. Some maintenance may be required by component failure or in emergencies. By definition, emergency maintenance is unplanned, but the site may proactively consider failures that could result in emergencies, plan maintenance to enact in these events, and post signage to avoid compounding hazards resulting from system failures. System or equipment failures should be investigated to determine causes and identify future preventative measures. Root cause analysis tools may prove useful in such cases.

Formal Maintenance Schedules

Formal maintenance scheduling and recordkeeping are important to ensure that maintenance occurs as scheduled or as needed and is documented. The site may be required by regulatory authorities to maintain certain types of maintenance records.

Gas Collection System. The gas collection system is subject to a variety of stresses from the site environment such as system collapse caused by waste settlement, corrosion or aging of materials (including ultraviolet degradation), and damage that might occur as a result of heavy equipment and vehicles coming into contact with the wells and piping. Typical gas collection system maintenance activities include:

- Repair or replacement of damaged wells and valves
- Removal of leachate and condensate blockages
- Repair of system components damaged by vehicles
- Re-grading or replacement of pipe affected by settlement of the waste mass
- Replacement of components that have failed as a result of aging or fatigue

Major repairs may require the temporary shutdown of the blower and flare system.

Blower and Flare System. Blowers are subject to vibration, belt wear, bearing deterioration and seal damage. Wear necessitates regular routine and scheduled maintenance as well as particular attention to sounds during system startup and shutdowns. Flares are subject to thermal stress that can be exacerbated if the flare is operated at temperatures or flows above manufacturer recommendations. Maintenance generally involves inspecting the flare for heat damage, maintaining pilot fuel and igniters, preventing condensate buildup and checking the general mechanical condition. Source testing can be used to assess flare performance.

Monitoring System Quality Assurance Requirements for Greenhouse Gas Projects

GHG emission reduction projects rely on monitoring to generate and monetize emission reduction credits. Because of this reliance, the relevant project protocol or developer will typically prescribe various monitoring requirements, including tolerances, meter locations and calibration frequencies within the quality assurance/quality control (QA/QC) procedures.

The purpose of QA/QC procedures associated with monitoring systems is to demonstrate that monitoring systems are operating correctly, that appropriate procedures for maintenance and calibration are performed, and that the parameters measured (flow rate, flare temperature, and methane content) are both accurate and within the prescribed tolerance. QA/QC procedures also include specific data retention requirements to demonstrate GHG emission reductions are verifiable, typically at annual intervals.

Best Practices for Design, Construction and Operation of Landfill GCCSs

The foundation of any LFGE project involves the design, construction, and operation of an LFG GCCS. GCCSs require proper engineering design, construction and operation by trained personnel to maximize intended benefits. While use of proper techniques and quality assurance procedures during construction help to ensure proper system operation and reliability, it is the operation of the GCCS that determines the success of the LFGE project. With periodic monitoring and adjustments to the GCCS, stakeholders will be able to adapt to constantly changing SWD site conditions.

CHAPTER 4

Landfill Gas Energy Utilization Technologies

There are several ways to effectively utilize LFG for energy; however, the primary applications are direct use and electricity generation technologies. This chapter provides an overview of LFGE utilization technologies, including emerging technologies that are not yet widely used but may prove feasible in certain situations. This chapter also discusses how to evaluate and select potential energy utilization technologies and concludes with a discussion of LFG treatment options.

Table 4-1 shows the installed generating capacity for electricity projects in Australia, Canada, the United Kingdom and the United States and in developing countries or countries in transition based on recently available data. In addition to these operational electricity projects, the CDM and JI databases show that an additional 219 megawatts (MW) of generating capacity is planned at landfill sites that have registered their projects with the UNFCCC.

Table 4-1. Installed Electric Generating Capacity from LFGE Plants for Select Countries

Country	Developing/Transitioning Countries		Australia	Canada	United Kingdom	United States
	CDM	JI				
Capacity (MW)	242	13	164	67	1,012	1,730

Sources: United Nations Environmental Programme (UNEP) CDM Pipeline spreadsheet and JI Pipeline spreadsheet as of 1 October 2011; Australian Department of Sustainability, Environment, Water, Population and Communities - Map of operating renewable energy generators in Australia as of 6 August 2010; Department of Energy and Climate Change, Digest of United Kingdom Energy Statistics (DUKES) as of 2010; Global Methane Initiative (formerly prepared under Methane to Markets Partnership) Landfill Subcommittee Country-Specific Profile and Strategic Plan for Canada as of 2005; U.S. EPA LMOP Landfill and LFG Energy Project Database as of 30 September 2011.

Although a similar level of recent detailed statistics is not available for all of the other types of projects, data on direct-use projects are available from a few GMI Partner Countries. Canada reported 10 direct-use projects in 2010 used for heating and industrial applications at refineries and gypsum manufacturing plants.[1] The United States reports 152 direct-use projects on line as of September 2011; these projects are used in multiple sectors of the economy—from institutions such as schools, hospitals, and military bases, to commercial greenhouses and aquaculture, to manufacturing of cement, paper, food and automobiles.[2] According to the CDM and JI databases, 38 projects are currently flaring their LFG and have been issued credits by the UNFCCC and another 50 projects are registered with the UNFCCC. These 88 projects provide significant opportunity for increased LFGE utilization in direct-use or electricity projects.

Both in-country and foreign project developers must consider that LFGE projects, even those using the same or similar technologies, vary widely in terms of costs as a result of project- and country-specific factors such as business risk, duties and taxes, availability of materials,

Project Feasibility

The feasibility of an LFGE project for a particular landfill will depend on numerous technical and economic considerations, such as waste composition and volume, quality and quantity of LFG, availability and location of a suitable end user, project capital and operation and maintenance (O&M) costs, and financing options.

[1] Global Methane Initiative (formerly prepared under Methane to Markets Partnership) Landfill Subcommittee. 2005. *Country-Specific Profile and Strategic Plan for Canada.* http://www.globalmethane.org/documents/landfills_cap_canada.pdf.
[2] U.S. EPA LMOP. Landfill and LFG Energy Project Database. http://www.epa.gov/lmop/projects-candidates/.

labor costs, permitting and possible project revenue streams. In addition, foreign project developers must also consider currency risk. (See Chapter 7, Project Economics and Financing, for a more detailed discussion of LFGE project cost considerations.)

4.1 Direct-Use Technologies

Figure 4-1. Installing a HDPE LFG pipeline for the Brazil MARCA Landfill in Cariacica, Brazil

In the United States, Australia, and many European countries such as Sweden, Germany and the Netherlands, LFG has been commercially used in place of a conventional fuel such as natural gas, fuel oil or coal for more than 30 years.[3] While LFG has been used for less time in other countries, direct-use technologies have proven to be both viable and environmentally beneficial. In this application, the collected LFG is used on site or sent to a nearby end user through a dedicated pipeline typically constructed of high density polyethylene (HDPE) (see Figure 4-1) or other materials such as stainless steel. The length of the pipeline will primarily determine the economic feasibility of the project. Pipelines constructed within 8 kilometers (km) of the landfill are often economically viable, but longer pipelines can prove economical based on the amount of LFG collected, the fuel demand of the end user, and the price of the fuel the LFG will replace. Pipelines must include facilities to remove condensate, either before it enters the pipe or at stages along the way. LFG can be combusted in boilers or other equipment that can be modified to utilize LFG, such as dryers, space heaters, kilns, furnaces, reformers, gas chillers and other thermal applications. LFG use is well suited for operations that have a steady and continuous demand for fuel. Batch processes that have fluctuating energy demands are not as desirable, as decreased LFG demand would result in excess flared LFG.

Boilers

Boilers use LFG as a fuel to produce steam or hot water (see Figure 4-2). The steam produced by the boiler can be used for space heating, process heating or electricity generation via a steam turbine.

Existing boilers usually require modifications to the burner and to the fuel train (for example, integrating the LFG fuel supply piping) to utilize LFG, but virtually any commercial or industrial boiler can be retrofitted to fire LFG or co-fire LFG with another fuel. The equipment for retrofitting boilers is commercially available and widely used, but site-specific considerations must be taken into account during the engineering and design phase. In particular, the quantity of LFG available must be considered and compared with the facility’s steam needs and

Figure 4-2. LFG Water Boiler System at the Gaoantun Landfill in Beijing, China

[3] U.S. EPA LMOP. Landfill and LFG Energy Project Database. http://www.epa.gov/lmop/projects-candidates/index.html. and IEA Bioenergy. 2003. “Municipal Solid Waste and its Role in Sustainability.” http://www.ieabioenergy.com/media/40_IEAPositionPaperMSW.pdf.

the boiler's capacity.[4] The costs associated with retrofitting boilers will vary depending on boiler type, fuel use, and age of the unit.

In addition to the burner and fuel supply piping modifications, retrofits include either automatic or manual process controls to control the fuel feed and the operation of the boiler. Typical approaches include:

- Installing automatic process controls and a dual-fuel train to blend LFG with other fuels to sustain a co-firing application or to provide for immediate fuel switching in the event of a loss in LFG pressure to the unit. This retrofit will ensure uninterruptible steam supply and provide users with the flexibility of dual-fuel firing.
- Installing manual controls on the boiler in lieu of an automatic process control system. This retrofit is best suited for scenarios where the boiler does not need immediate uninterruptible steam supply if there is a loss of LFG pressure to the boiler, or where other units in the system are available to provide back-up steam supply. In this case, manual controls are implemented and the boiler operating system is not integrated in an automatic process control system.[5]

LFG has been used in a wide range of boiler sizes, from small package boilers used to heat maintenance buildings, schools and hospitals to large industrial units, providing steam for pulp and paper, automobile and other large manufacturing processes. LFG is corrosive (unless very well dried) and may affect conversion of standard boiler equipment. Table 4-2 shows the estimated sizes of LFG boiler installations in the United States for specific applications.

Use of LFG in Boilers

For more information about the use of LFG in boilers, see the LMOP fact sheet on boiler retrofitting.

Table 4-2. Typical LFG Boiler Sizes

Technology/Application	Energy Demand (MJ/hr)	Estimated LFG Flows (m^3/hr)*
Small Package Boiler: School, Hospital or On-site Landfill Heating	200 to 6,700	11 to 350
Mid-Sized Hospital Boiler	17,000 to 22,200	880 to 1,200
Industrial Steam Boiler	9,600 to 160,000	510 to 8,500

* Assuming 50 percent methane in the LFG. Source: U.S. EPA LMOP Landfill and LFG Energy Project Database as of April 2011.

Examples: LFG Used in Boilers

As of 2011, the Gaoantun Landfill in Beijing, China had an average gas flow of 2,500 cubic meters per hour (m^3/hr) at 60 percent CH_4. A portion of the LFG is used in a boiler to supply hot water in the washroom at the landfill. See Appendix A for a case study of the Gaoantun Landfill.

The Three Rivers Regional Landfill in South Carolina, USA uses LFG to fuel a boiler to provide steam for the Kimberly-Clark Beech Island paper mill.

[4] U.S. EPA LMOP. 2009. *Adapting Boilers to Utilize Landfill Gas: An Eivronmentally and Economically Beneficial Opportunity*. http://epa.gov/lmop/documents/pdfs/boilers.pdf.

[5] Global Methane Initiative. 2010. *Landfill Gas Energy Technologies.* http://www.globalmethane.org/Data/1022_LFG-Handbook.pdf.

Furnaces, Dryers and Kilns

Figure 4-3. Glass Studio at the EnergyXchange Renewable Energy Center in North Carolina, USA

Furnaces, dryers and kilns can use LFG as a replacement for or supplement to conventional fuels (see Figure 4-3) in cement, brick and ceramics, iron and steel, wood products manufacturing and other sectors. For small applications (such as local brick or pottery plants) LFG may supply all or most of the energy needs. For plants with larger energy consumption, there often will not be a sufficient supply of LFG to meet 100 percent of the fuel needs at the manufacturing plant, and so LFG is often used as a supplementary fuel. In these scenarios, LFG provides cost savings to industries with highly energy intensive processes, especially for manufacturers relying on imported or unstable fuel supplies.

Typically, only very limited gas treatment (for example, condensate removal and filtration) is required for these uses, but some modification of combustion equipment may be necessary to accommodate the low heating value of LFG. From an environmental standpoint, the equipment that combusts the fuel must have a suitable retention time and temperature to ensure adequate destruction efficiency of trace gas components in the LFG.

In addition to industrial uses, some municipalities have used LFG to fuel rotary drum dryers or sludge incinerators for their local wastewater treatment plants. Often landfills and wastewater treatment infrastructures are adjacent to one another and LFG can offset wastewater treatment costs for the municipality. For example, the pelletized, treated and dehydrated biosolids can be sold to fertilizer manufacturers[6]. Table 4-3 shows the typical sizes of LFG direct thermal projects in the United States.

Table 4-3. Typical Sizes of Other LFG Direct Thermal Projects

Technology/Application	Estimated LFG Flows (m^3/hr)*	Installations in United States
Dryers: Municipal Sludge Dryers	470 to 1,300	4
Dryers: Industrial Applications	1,400 to 3,100	3
Furnaces: Iron and Steel Industry	510 to 2,400	3
Kilns: Brick and Cement Industries	680 to 3,400	12
Community Artisan Activities (Pottery, Glassblowing and Metallurgy)	34 to 68	3

* Assuming 50 percent methane in the LFG. Source: U.S. EPA LMOP Landfill and LFG Energy Project Database as of April 2011.

✔ Examples: LFG Used for Artisan Activities and Brick Manufacturing

The Yancey-Mitchell County Landfill, located in North Carolina, USA, is the site of the EnergyXchange Renewable Energy Center where captured LFG is used to run pottery kilns and glass furnaces, in addition to supplying radiant heat for a greenhouse and other buildings located on the landfill.

LFG from the Star Ridge Landfill in Alabama, USA, is used as a fuel for the Jenkins Brick Company manufacturing plant.

See Appendix A for case studies of the Yancey-Mitchell County and Star Ridge landfills.

[6] Public Works Magazine, January 2011. *Self-Sustaining Biosolids Drying*. http://www.pwmag.com/industry-news.asp?sectionID=760&articleID=1481422.

Infrared Heaters

Infrared heaters create high-intensity energy (heat) that is safely absorbed by floors and objects in a space (see Figure 4-4). Infrared heaters are effective for spot heating and are also used for heating large areas.[7] There are two kinds of LFG infrared heaters in use: ceramic (bright) and pipe (dark or low-intensive). Ceramic infrared heaters are made up of a perforated ceramic board covered with an aluminum reflector and an electrovalve that intakes a mixture of gas and air. Ceramic infrared heaters usually operate at temperatures between 800°C and 1,000°C and have efficiencies as high as 93 percent. Pipe infrared heaters are composed of a gas burner, a radiating pipe, and a screen and operate at temperatures between 400°C and 600°C. The radiating pipe is made of steel and titanium and is covered with black silicon emulsion, which contributes to the heater's radiating capacity.

Figure 4-4. Infrared Heater at the Khmelnitsky Landfill in Ukraine

Example: LFG Used for Infrared Heating

The Khelmintsky Landfill in Ukraine uses LFG to power infrared heaters installed at the landfill garage. The infrared heaters convert LFG energy into heat energy that is safely absorbed by surfaces. The project included the design and construction of a gas collection and treatment system and installation of horizontal pipelines.

Infrared heating, using LFG as a fuel source, has been successfully employed at several landfill sites in Canada, the United States, and the Ukraine. It is ideal when a facility with space heating needs is located at or near the landfill, such as an on-site maintenance building for sanitation workers. Depending on the location, the infrared heater may only be needed seasonally, which may limit LFG use. Infrared heaters require a small amount of LFG and are relatively inexpensive and easy to install and operate. Current heater projects use as little as 20 to 50 m^3/hr LFG, and less than 50 m^3/hr of LFG is needed to heat about 600 square meters (m^2) of space.[8] Infrared heaters require no or minimal LFG treatment, unless there are siloxanes in the gas.

Leachate Evaporation

LFG can also be used directly to evaporate leachate, which reduces leachate treatment and hauling costs by evaporating this liquid to a more concentrated and more easily disposed of effluent volume (see Figure 4-5). Leachate evaporation is a good option for landfills where leachate disposal is not available or is expensive, or where there are high volumes of leachate competing with space constraints at the landfill. However, certain byproducts of leachate evaporation (such as concentrated liquids or salts) should be safely disposed of or treated. Direct discharge leachate evaporators have low LFG requirements; modern direct discharge designs require approximately 330 m^3/hr of LFG to evaporate 1,670 liters per hour (l/hr) of leachate.[9]

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[7] D.T. Mears, Optimum Utility Systems. 2001. *Biogas Applications for Large Dairy Operations: Alternatives to Conventional Engine-Generators*. http://www.manure.umn.edu/assets/cornell_biogas_applications.pdf.

[8] D.D. Dillah, January 2006. *Heating Landfill Facilities Using Infrared Heaters – Part 2 and Project 2.* http://www.epa.gov/lmop/documents/pdfs/conf/9th/dillah.pdf.

[9] Shaw LFG Specialties, LLC. 2007. *The Future of LFG Utilization*. http://www.globalmethane.org/expo_china07/docs/postexpo/landfill_zeng.pdf.

There are three categories of commercial leachate evaporation systems: spray-type dryers, direct injection-devices, and — the most commonly used — evaporation vessels. The primary features distinguishing these various leachate evaporation systems are their methods for transferring heat to leachate and treating the exhaust vapor.

Most available commercial systems use direct-contact evaporative technology, where heat is transferred by direct contact between the leachate and the hot combustion gas. Depending on the manufacturer of the evaporator, the LFG combustion unit can be located on top of the evaporation vessel, where the hot combustion gas is bubbled through a small pool of leachate at the bottom of the vessel, or on the side of the vessel, where the hot combustion gas is exhausted through submerged pipes within the vessel.

Some commercial systems use indirect transfer. In this technology, heat is transferred indirectly from an LFG burner through the walls of the heat exchanger to the leachate. Precipitated solids in the leachate may cause scale build-up on heat transfer surfaces, so regular cleaning is required for proper performance.[10]

Figure 4-5. Leachate Evaporator System at El Verde Landfill in León, Mexico

✔ Example: Leachate Evaporation

An example of the use of leachate evaporators is at the El Verde Landfill in León, Mexico, where a 1,890 l/hr leachate evaporator has operated since 2010. See Appendix A for a case study of the El Verde Landfill.

4.2 Electricity Generation Technologies

LFG can be used as a fuel in internal combustion engines or combustion turbines driving either an electrical or gas-powered generator. The generated electricity can be used to power on-site needs such as the blowers for the active gas collection system or leachate treatment system or, more typically, be sold to the local electricity grid.[11] Electricity generation from LFG accounts for the majority of LFGE projects globally.

Internal Combustion Engine

The most common LFG utilization technology for small to relatively large LFGE projects is the internal combustion engine (Figure 4-6). Internal combustion engines are available in various sizes with electrical outputs ranging from less than 0.2 MW to more than 3.0 MW per unit.[12] Between 500 and 540 m^3/hr of LFG at 50 percent methane is necessary to generate 1 MW of electricity. Internal

Figure 4-6. GE Jenbacher Internal Combustion Engine at Simprodeso Landfill in Monterrey, Mexico

[10] Global Methane Initiative. 2010. *Landfill Gas Energy Technologies.* http://www.globalmethane.org/Data/1022_LFG-Handbook.pdf.

[11] ISWA. *ISWA Landfill Operational Guidelines*. 2nd Edition. http://www.wief.net/programs_events/ISWA_Landfill_Operational_Guidelines_2nd_Edition[1].pdf.

[12] Loening A. November 2010. “Biogas Technology Applications.” http://www.globalmethane.org/documents/events_land_20101209_loening.pdf.

combustion engines that use LFG as a fuel are commercially available and may be obtained as modular units or within a complete parallel generator package. Often, containerized systems are installed in a series to allow for engines to be added or removed in response to fluctuating gas flows over time. Many manufacturers have designed engines specifically to operate on LFG and other biogases, and they should be able to provide examples of these operations.

✓ Examples: LFG Use for Electricity Generation

Examples of LFG use for electricity generation are:

- The LFGE project at the Loma Los Colorados Landfill in Santiago, Chile, started with an electricity generation capacity of 2 MW in 2009. Currently Phase II is in operation, reaching approximately 11.89 MW of installed capacity. Phase II will include an additional 9.9 MW, and Phase III will consist of the installation of an additional 21.78 MW capacity.
- São João Landfill in São Paulo, Brazil has been operating an LFGE system since 2007 with an installed capacity of 22 MW. See Appendix A for a case study of São João Landfill.

Gas Turbines

A larger LFGE technology example is the gas turbine. LFG-fired gas turbines are similar to natural gas turbines except that, because of the lower pipeline quality value, twice the number of fuel regulating valves and injectors are used.[14] The majority of gas turbines currently operating at landfills are simple cycle, single-shaft machines. Gas turbines are generally larger than internal combustion engines and are available in various sizes from 1 MW to more than 10 MW (see Figure 4-7).[15] Although smaller gas turbine units or “microturbines” (1 MW) have been used at landfills, they are not normally the primary generating unit. Most LFGE projects using turbines in the United States are in the 3 to 5 MW range, which require sustainable LFG flows in excess of 2,000 m^3/hr. Gas turbines are available as modular and packaged systems. Modular systems allow for flexibility in responding to changes in LFG quality and flow.

Figure 4-7: Dual Gas Wide Wobbe Fuel Assembly and Fuel Injectors on a Solar LFG Turbine[13]

Gas turbines require a high pressure fuel supply in the range of 165 to 200 pounds per square inch gauge (psig); thus, a fuel gas compressor (FGC) must precede the turbine. The FGC is the more sensitive piece of equipment for the efficient long-term reliability of the facility. Requirements for the compression stage will typically govern the level of LFG processing that will be necessary to ensure reasonable operating and maintenance costs for the facility. The required LFG pressure can consume a significant portion of the power being generated, resulting in lower energy conversion efficiencies (parasitic losses).

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[13] Middough. City of Toledo, OH Landfill Gas 10 MW Combined Cycle Cogeneration Facility. http://www.middough.com/Business/Industrial/Energy.aspx.

[14] SCS Engineers. 1997. *Comparative Analysis of Landfill Gas Utilization Technologies.* http://www.nrbp.org/pdfs/pub07.pdf.

[15] Ibid, Loening.

Combined Heat and Power

Some electricity projects can increase their operating efficiencies by incorporating cogeneration systems. Combined heat and power (CHP) or cogeneration systems generate electricity and capture waste heat to provide thermal energy. Thermal energy cogenerated by LFG electricity projects can be used for on-site heating, cooling, or process needs, or piped to nearby industrial or commercial users to provide a second revenue stream for the project.[16] CHP is often a better economic option for end users located near the landfill or for projects where the end user has sufficient demand for both the electricity and the waste heat.[17]

Example: LFG Use for CHP

An example of LFG as a fuel source for CHP is YTV Ämmässuo Landfill in Finland. This project utilizes LFG for district heating and power generation.

Biomass CHP Catalog of Technologies

For additional information about CHP, see the U.S. EPA Combined Heat and Power Partnership's Biomass CHP Catalog of Technologies.

4.3 Emerging LFG Recovery Technologies

In addition to the commonly used direct-use and electric generating technologies discussed above, there are several emerging technologies that show promise for LFGE recovery internationally. These technologies are not used on a wide-scale basis but may prove technically and economically feasible under certain conditions.

LFG Conversion to High-Pipeline Quality Gas

LFG can be purified to produce the equivalent of pipeline-quality gas (natural gas), compressed natural gas (CNG), or liquefied natural gas (LNG). The pipeline-quality gas can be injected into a natural gas pipeline and used for industrial purposes. CNG and LNG can be used to fuel vehicles at the landfill or supply vehicle fleets designed to use these fuels. It is necessary for gas fuel produced from LFG to satisfy fuel quality standards set by regulatory agencies or by independent organizations for LFG-derived fuels to be considered interchangeable with gas fuels.[18] To meet these standards, extensive LFG treatment is needed to greatly increase the methane content of the gas and decrease the carbon dioxide, nitrogen, oxygen and moisture contents. Current gas treatment technologies are relatively expensive; membrane or pressure swing absorption gas purification processes require additional gas compressors to be installed, and the O&M of these systems can be relatively complex. LFG purification projects have generally been implemented only at very large landfills or where there is a high demand for CNG or LNG and occur more often in the United States than other countries. In addition, tight management of gas collection system (wellfield) operation may be needed to limit intrusion of oxygen and nitrogen into LFG. The primary cause for the presence of oxygen and nitrogen

Additional Information

Additional information on the conversion of LFG to high-quality pipeline gas can be found in Chapter 3 of the LMOP LFG Energy Project Development Handbook.

[16] U.S. EPA Combined Heat and Power Partnership. *Catalog of CHP Technologies.* http://www.epa.gov/chp/documents/catalog_of_%20chp_tech_entire.pdf.

[17] U.S. EPA. 2012. *Landfill Gas Energy: A Guide to Developing and Implementing Greenhouse Gas Reduction Programs*. http://www.epa.gov/statelocalclimate/documents/pdf/landfill_methane_utilization.pdf.

[18] Pierce, J. SCS Engineers. 2007. *Landfill Gas to Vehicle Fuel: Assessment of Its Technical and Economic Feasibility.* SWANA 30th Annual Landfill Gas Symposium (4-8March, 2007), Monterey, California. http://www.scsengineers.com/Papers/Pierce_LFG_to_Vehicle_Fuel_SWANA2007.pdf.

in LFG is air that is drawn through the surface of the landfill and into the gas collection system. Air intrusion can often be minimized by adjusting well vacuums and repairing leaks in the landfill cover.

Pyrolysis Furnace

Pyrolysis is a type of low-temperature waste incineration that occurs under near anaerobic conditions. Pyrolysis technology can be used to destroy semivolatile organic compounds in waste materials such as infectious wastes from hospitals. In a pyrolysis furnace, the waste material is converted to a combustible gas or liquid that can then be used to help fuel the furnace. A furnace can use LFG as a supplemental fuel source and does not require a large amount of LFG—a gas flow as low as 170 m^3/hr may be sufficient.

Anaerobic Digestion

Although not an LFGE recovery technology, anaerobic digestion (AD) of MSW is being demonstrated at some landfill sites as an alternative to landfilling and capturing methane emissions from the waste stream. AD is also used in some communities to process separately collected food waste streams. Two primary methods of AD are in-vessel or in-ground designs. The in-vessel design, which includes a constructed aboveground container to hold the organic wastes (see Figure 4-8), is widely used in the sewage treatment industry. The aim of in-vessel designs for MSW is to accelerate the decomposition rate at the thermophylic stage to achieve elevated methane production rates. In contrast, in-ground designs, such as covered, in-ground anaerobic reactors (CIGAR), install a flexible cover over the organic fraction of MSW; this design is widely used in animal manure or industrial wastewater projects. For MSW, in-ground designs would require liquefying the organic fraction of waste before it is circulated through the reactor. Typically, the MSW in the reactor is inoculated with leachate and the waste decomposition would occur at lower temperatures, typical of the mesophylic stage of decomposition. The organic fraction of MSW (or separately collected food waste) is used as a feedstock in an enclosed digester, where it is decomposed by bacteria under controlled anaerobic conditions to produce digester gas, which contains medium-to-high concentrations of methane, and is typically used to produce electricity. With digesters, virtually 100 percent of the gas produced is captured and used (whereas the gas collection efficiency from landfills is lower).

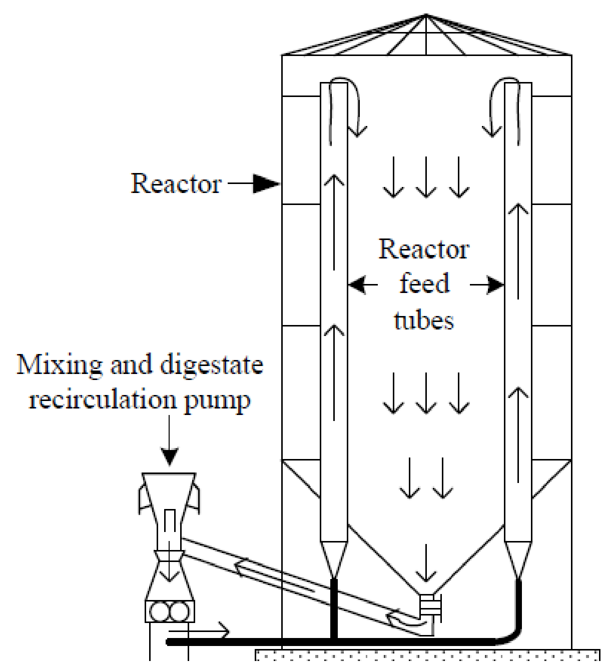

Figure 4-8. Schematic of a Dranco system In-Vessel Anaerobic Digester[19]

[19] "Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste." California Integrated Waste Management Board.

4.4 Selection of Suitable Technologies

For landfills pursuing LFGE recovery, the primary choices are electricity generation technologies or the direct use of LFG as a fuel. The best type of energy recovery technology for a particular landfill will depend on a number of factors. General considerations for selecting appropriate LFGE technologies include:

- Guarantee of waste delivery (composition and volume)
- Distance to the grid
- Local and regulatory framework
- Quantity and duration of LFG recovery potential
- Presence of nearby potential end users for direct use of LFG
- Ability to sell electricity to the grid (infrastructure and regulatory framework)
- On-site needs for heat or electricity
- Capital expenditures and operating costs of utilization system options, including gas treatment and transportation issues and costs
- Financial considerations (expected revenues from the sale of LFG for electricity or direct use, carbon credits, other financial incentives, mode of financing, and return on investment) — see Chapter 7
- Availability of local suppliers to provide and service equipment
- Availability of skilled operators to operate and maintain equipment
- Ability to secure contracts (energy purchase and sales and gas rights agreements) — see Chapter 5

Direct Thermal Use Considerations

The major benefits of direct thermal applications are that they maximize utilization of the gas, require limited treatment, and allow for blending with other fuels. Direct thermal applications have been demonstrated for a wide range of project sizes as long as there is a match between the quantity of LFG available and the demands of a prospective end user, or adequate LFG to supplement the primary fuel consumption of the end user. Direct thermal applications may be most useful when electricity regulations or markets restrict the sale of electricity generated from LFG (see Chapter 5 for additional information on electricity markets).

Factors to consider in evaluating the suitability of a direct thermal project include:

- ***Energy requirements of the end user in terms of quantity and quality of LFG.*** The quantity of LFG available and its methane content must be considered and compared with the facility's heat or steam needs and rated heat input capacities of the combustion equipment. End users with large daily or seasonal fluctuations in fuel demand are less desirable, as LFG is produced at the site at a relatively constant rate and it is not feasible to store LFG for delayed consumption at the facility.[20] In addition, the gas quality and type of LFG treatment needed for the specific end use must be considered in analyzing economic feasibility.
- ***Retrofit Requirements to Accommodate LFG.*** There are also considerations for the end user on designing equipment that either co-fires LFG and other supplementary fuels or that uses LFG as primary fuel with natural gas or other fuel as a back-up source only. The fuel train configuration will

[20] ESMAP. 2004. *Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean*. http://www.esmap.org/esmap/node/1106.

need to be modified to add an LFG burner and control system to accommodate the fuel sources selected, as discussed in Section 4.1. Burner modifications and changes in the process control systems will also be required for boiler applications. Kilns such as those used in the brick and cement manufacturing industries typically tolerate a wide range of fuel quality and may have lower retrofit costs.

- ***Location of the end user.*** The location of the end user will dictate the necessary length and location of an LFG pipeline. The landfill must be located relatively near an end user (generally less than 10 or 15 km) to achieve an adequate return on investment for this type of LFGE project, as the capital and operating costs of a dedicated pipeline longer than 10 km can make the net cost of delivered LFG less competitive with traditional fuels. However, a longer distance may be economically feasible, depending on the amount of gas recovery at the landfill, the energy load of the end-use equipment, and fuel prices.[21] Additionally, the end user's location will determine the route of the pipeline. Crossing railroads, waterways, or major roadways will factor into the cost and feasibility of pipeline construction.
- ***Cost considerations.*** The costs associated with gas treatment, pipeline and conversion of equipment to utilize LFG, as well as O&M, must be considered. The economics of an LFGE project improve the closer the end user is to the landfill. Furthermore, pipeline right-of-way issues will influence costs and the price at which LFG can be delivered and sold to the end user.[22] In addition, the end user must invest in equipment that is capable of switching between LFG and traditional fuels to manage the long-term uncertainty and variability of LFG flow, as well as pipeline quality value. The long-term financial stability of the end user should also be considered. (To recover the project investment cost, a 10- to 15-year project lifetime is usually required.) Refer to Chapter 7 for more information on project costs.

Factors to consider in determining suitability of on-site LFG usage include:

- ***Infrared heater or other space heating considerations.*** The low volume of LFG required for infrared heater projects or small boilers used for heating schools or administrative buildings and the seasonal nature of heating requirements may make these projects cost prohibitive on their own if the landfill does not already have a gas collection and flaring system. However, infrared heaters work well when paired with another flaring and or energy project at the site because the infrared heater can use a small amount of leftover gas that would otherwise be flared.
- ***Leachate evaporation considerations.*** Leachate evaporation systems are generally economically feasible only at sites where there is an adequate supply of LFG to evaporate the volume of leachate generated and the costs for alternative methods of leachate treatment and disposal are high. A typical landfill requires approximately 0.15 m^3 to evaporate 1 liter of leachate.[23] Evaporators are available in a range of sizes, and some economies of scale are realized for larger size vessels.

[21] World Resources Institute. 2002. *Opportunities with Landfill Gas*. http://pdf.wri.org/gpmdg_corporate_guide_02.pdf.
[22] U.S. EPA. 2012. *Landfill Gas Energy: A Guide to Developing and Implementing Greenhouse Gas Reduction Programs*. http://www.epa.gov/statelocalclimate/documents/pdf/landfill_methane_utilization.pdf.
[23] Instytut Nafty i Gazu. 2010. *Landfill Gas Energy Technologies*. http://www.globalmethane.org/Data/1022_LFG-Handbook.pdf.

Electricity Generation Considerations

The geographic limitations and need for equipment modification associated with direct use can be overcome by using LFG to fuel electricity generation equipment located at the landfill. In general, internal combustion engines have proven to be the most cost-effective and reliable technology for electricity generation from LFG, especially for moderately sized projects. Gas turbines are an option for LFGE projects that can support generation capacity of at least 3 to 5 MW.[24] Other factors that should be evaluated in considering electricity generation from LFG, include:

- ***Electrical conversion efficiency.*** Electrical conversion efficiency is an indication of what portion of the energy value of the LFG can be converted into electrical power. Electrical conversion efficiency varies based on the selected technology. Internal combustion engines have a higher efficiency than most gas turbines. However, very high altitudes or high ambient temperatures reduce the efficiency of internal combustion engines.
- ***Power generation potential.*** Reliability of the power generation equipment and the supply of the fuel to the LFGE plant will determine the actual amount of power generation.
- ***LFGE plant maintenance and repair.*** The need and extent of any recommended spare parts must be assessed based on the availability of these parts in the specific country, as well as the time that may be required to import the parts.[25] Operating the LFGE plant in accordance with equipment specifications and conducting regularly scheduled maintenance will reduce the wear on system parts and allow plant operators to plan for outages, thereby reducing plant downtime. Developing a plan for routinely conducting and tracking analysis of engine oil is important to help the plant operators assess operational problems early in the process.
- ***Ability to respond to changes in LFG quantity over time.*** The modular nature of internal combustion engines and gas turbines provides flexibility for incremental capacity increases in response to greater production of LFG.[26] Internal combustion engines or microturbines can be added in smaller incremental stages than gas turbines for a lower capital cost.
- ***Availability of an electric grid interconnection point.*** Typically, LFGE projects rely on existing infrastructure to deliver electricity to the market because the costs of building extensive new infrastructure are prohibitive. The project developer should examine the availability and types of nearby power lines and electrical substations. Nearby power lines that are suitable to provide a connection to the power grid and substations are advantageous for project development. Interconnection can be a considerable investment cost and will require careful investigation into permits and approvals that can vary greatly, depending on the location and site-specific requirements.
- ***Cost considerations.*** Costs include capital and labor costs to purchase and install all equipment needed to treat the gas and generate electricity as well as ongoing O&M costs (labor and materials used to operate the system and perform routine maintenance and repairs, including periodic equipment overhauls). Internal combustion engines have a comparatively low capital cost per kilowatt (kW), but have higher O&M costs than gas turbines.[27] Refer to Chapter 7 for more information on project costs.

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[24] World Resources Institute. 2002. *Opportunities with Landfill Gas*. http://pdf.wri.org/gpmdg_corporate_guide_02.pdf.
[25] Ibid.
[26] ESMAP. 2004. *Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean*. http://www.esmap.org/esmap/node/1106.
[27] ISWA. *ISWA Landfill Operational Guidelines*. 2nd Edition. http://www.wief.net/programs_events/ISWA_Landfill_Operational_Guidelines_2nd_Edition[1].pdf.

4.5 Treatment of LFG

Before collected LFG can be used in a conversion process, it is usually treated to remove moisture (condensate) not already captured in the condensate removal systems, along with particulates and other impurities. Treatment requirements depend on the end use application. The primary treatment option for both electricity and direct-use technologies is moisture removal since LFG is saturated and can be corrosive to equipment. Minimal treatment is required for direct use of LFG in boilers, furnaces or kilns. Treatment systems for LFG electricity projects typically include a series of filters to remove contaminants that could damage components of the engine and turbine and reduce system efficiency. The focus of this section is on the treatment conducted before direct-use and electricity projects.

Types of Treatment Systems

Treatment systems can be divided into primary treatment processing and secondary treatment processing. Most primary processing systems include de-watering and filtration to remove moisture and particulates. Dewatering can be as simple as physical removal of free water or condensate in the LFG through a relatively simple device — a condensate knockout pot (see Figure 4-9). The condensate knockout pot slows the gas velocity sufficiently for gravity settling or "knock-out" of liquid to occur. Knockout pots should be located as close to the inlet to the gas booster as practicable. The liquid can then be drained or pumped to a discharge storage tank. Knockout pots are capable of handling large gas flows (greater than 10,000 m^3/hr) and of removing more than 1 liter per minute of water.[28]

Figure 4-9. Knockout Pot Upstream of Flare at Gaoantun Landfill, China

It is common in new projects to remove water vapor or humidity in the LFG by using gas cooling and compression. Cooling the LFG causes condensation of the water vapor, which in turn results in dehumidification. The condensate is separated out in a trap installed after the cooling equipment and removed via a siphon or pump. Typical temperatures for gas cooling range from -4° to 10°C. Gas compression prior to cooling serves to further dehydrate the air. Gas compression is commonly specified by the distance to the energy recovery systems and by their input pressure requirements, and commonly ranges from less than 100 to nearly 700 kilopascal (kPa). LFG dehumidification results in increased efficiency and protects LFG equipment. Chlorinated and halogenated compounds and other water-soluble compounds are also removed with the condensate.[29]

Secondary treatment systems are designed to provide much greater gas cleaning than is possible using primary systems alone. Secondary treatment systems may employ multiple cleanup processes depending on the gas specifications of the end use. These processes can include both physical and chemical treatments. The type of secondary treatment depends on the constituents that need to be removed for the desired end use. Two trace contaminants that may have to be removed from LFG are:

[28] United Kingdom Environment Agency. *Guidance on Gas Treatment Technologies for Landfill Gas Engines*. http://publications.environment-agency.gov.uk/pdf/GEHO0311BTON-e-e.pdf.

[29] ESMAP. 2004. *Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean*. http://www.esmap.org/esmap/node/1106.

- ***Siloxanes:*** Siloxanes are found in household and commercial products that find their way into solid waste and wastewater (a concern for landfills that accept wastewater treatment sludge). The siloxanes in the landfill volatilize into the LFG and are converted to silicon dioxide when the LFG is combusted. Silicon dioxide (the main constituent of sand) collects on the inside of internal combustion engines and gas turbines and on boiler tubes, potentially reducing the performance of the equipment and resulting in significantly higher maintenance costs. The need for siloxane treatment depends on the level of siloxane in the LFG (which varies among landfills) and on manufacturer recommendations for the energy technology selected. The removal of siloxane can be both costly and challenging, so the decision to invest in siloxane treatment is project dependent. Figure 4-10 depicts the diagram of one type of siloxane removal system. Figure 4-11 shows the siloxane removal technology as installed at a landfill.

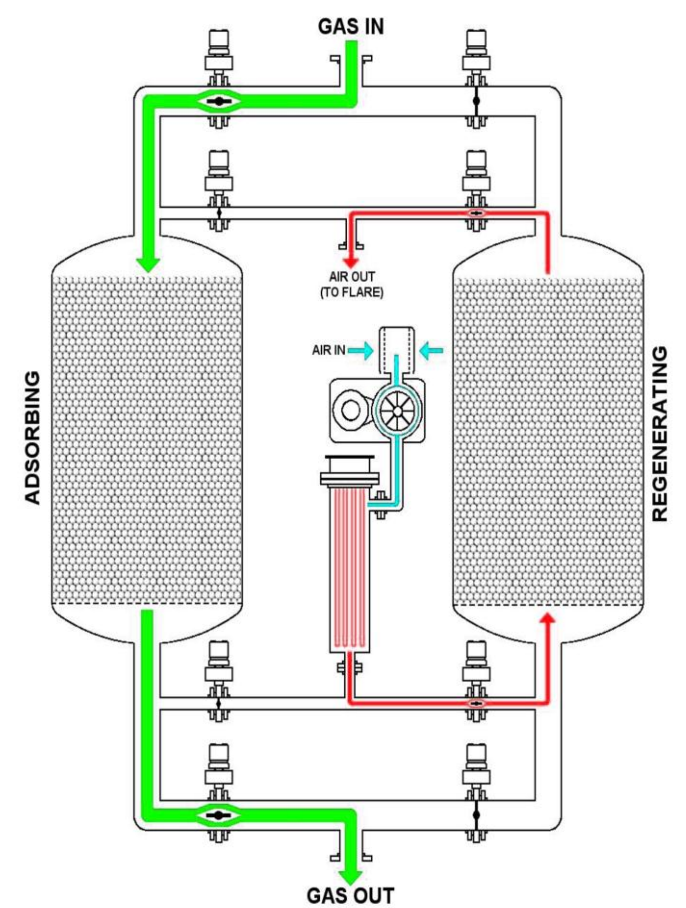

Figure 4-10. Diagram of the a siloxane removal system

Figure 4-11. Siloxane removal systems at the Lorraine power station at Oberlin, Ohio, USA

- ***Sulfur compounds:*** These compounds, which include sulfides and disulfides (hydrogen sulfide), are corrosive in the presence of moisture. These compounds will be relatively low and the LFG may not require any additional treatment at landfills accepting only typical MSW. The compounds tend to be higher in landfills that accept construction and demolition materials and additional treatment is more likely to be necessary.

The most common technologies used for secondary treatment are adsorption and absorption. Adsorption involves the physical adsorption of the contaminant onto the surface of an adsorbent such as activated carbon or silica gel. Adsorption has been a common technology for removing siloxanes from LFG. Absorption (or scrubbing) involves the chemical or physical reaction of a contaminant with a solvent or solid reactant. Absorption has been a common technology for removing sulfur compounds from LFG.

Filtration systems may be installed to provide additional LFG treatment. Particulates in the LFG stream that enter equipment can cause damage and wear. Particles can be controlled either by passing the gas stream through a filter pad (typically made of stainless steel wire or geotextile), or alternatively using a cyclone separator. Cyclones are capable of removing particles down to 15 micrometer (µm) (or even 5 µm for a high efficiency cyclone), whereas filter pads are effective down to 2 µm. Both systems are prone to blockage and thus require periodic maintenance to remove accumulated solids.

Treatment Cost Considerations

The treatment required for an LFGE project may range from the simple removal of moisture and particulates to the more expensive removal of corrosive and abrasive contaminants.[30] The specific type and application of LFG utilization equipment may require various levels of LFG treatment. The primary form of treatment for LFG is to remove some portion of the water vapor from the saturated LFG, which reduces the maintenance costs for the utilization equipment. Cleaner fuel gas can result in substantially reduced corrosion and reduced maintenance costs over the life of the equipment.[31] The level of LFG treatment and subsequent cost will depend on the gas purity requirements of the end use application. For example, siloxanes will cause fewer problems for boilers than for engines or turbines.

The tradeoff of simplified and less costly treatment is increased equipment maintenance. The treatment system is usually an upfront capital cost, whereas not using a treatment system or using a simplified treatment system will likely result in increased long-term O&M costs and ultimately equipment replacement costs. For most sites, a cooling system is recommended to cool, dehumidify, and filter the gas to remove free liquids and particulates before it is piped to engines or compressors. Other treatments for hydrogen sulfide or siloxanes depend on the project requirements and contaminant levels in the LFG.

In practice, landfill operators that have chosen not to install cooling systems have been able to run the engines, but have encountered problems with corrosion from acid formation and particulates in the combustion zone, resulting in more frequent oil changes and periodic maintenance, and in some cases extreme wear on engine cylinders. Lack of treatment causes a buildup of silicon compounds in components such as after coolers and turbochargers, which results in additional maintenance costs.

4.6 LFGE Technology and Cost Summary

Table 4-4 provides a summary of the LFGE technologies discussed in this chapter. Table 4-5 presents typical capital and annual costs for landfill gas projects, based on LFGE projects conducted in the United States.

[30] ISWA. *ISWA Landfill Operational Guidelines*. 2nd Edition. http://www.wief.net/programs_events/ISWA_Landfill_Operational_Guidelines_2nd_Edition[1].pdf.

[31] Ibid.

Table 4-4. Summary of LFGE Technologies

Advantages	Disadvantages	LFG Treatment Requirements
Direct-Use Medium Pipeline Quality		
Boiler, dryer, and process heater		
▪ Can utilize maximum amount of recovered gas flow ▪ Cost-effective ▪ Limited condensate removal and filtration treatment is required ▪ Does not require large amount of LFG and can be blended with other fuels	▪ Cost is tied to length of pipeline; energy user must be nearby	Need to improve quality of gas or retrofit equipment
Infrared heater		
▪ Relatively inexpensive ▪ Easy to install ▪ Does not require a large amount of gas ▪ Can be coupled with another energy project	▪ Seasonal use may limit LFG utilization	Limited condensate removal and filtration treatment is required
Leachate evaporation		
▪ Good option for landfill where leachate disposal is expensive	▪ High capital costs	Limited condensate removal and filtration treatment is required
Electricity		
Internal combustion engine		
▪ High efficiency compared with gas turbines and microturbines ▪ Good size match with the gas output of many landfills ▪ Relatively low cost on a per kW installed capacity basis when compared with gas turbines and microturbines ▪ Efficiency increases when waste heat is recovered ▪ Can add/remove engines to follow gas recovery trends	▪ Relatively high maintenance costs ▪ Relatively high air emissions ▪ Economics may be marginal in countries with low electricity costs	At a minimum, requires primary treatment of LFG; for optimal engine performance, secondary treatment may be necessary
Gas turbine		
▪ Economies of scale, because the cost per kW of generating capacity drops as gas turbine size increases and the efficiency improves as well ▪ Efficiency increases when heat is recovered ▪ More resistant to corrosion damage ▪ Low nitrogen oxides emissions ▪ Relatively compact	▪ Efficiencies drop when the unit is running at partial load ▪ Requires high gas compression ▪ High parasitic loads ▪ Economics may be marginal in countries with low electricity costs	At a minimum, requires primary treatment of LFG; for optimal turbine performance, secondary treatment may be necessary

Advantages	Disadvantages	LFG Treatment Requirements
Microturbine		
▪ Need lower gas flow ▪ Can function with lower percent methane ▪ Low nitrogen oxides emissions ▪ Relatively easy interconnection ▪ Ability to add and remove units as available gas quantity changes	▪ Economics may be marginal in countries with low electricity costs	Requires fairly extensive primary and secondary treatment of LFG
Direct-Use High Pipeline Quality		
Pipeline-quality gas		
▪ Can be sold into a natural gas pipeline	▪ Increased cost that results from tight management of wellfield operation needed to limit oxygen and nitrogen intrusion into LFG	Requires extensive and potentially expensive LFG processing
CNG or LNG		
▪ Alternative fuels for vehicles at the landfill or refuse hauling trucks, and for supply to the general commercial market	▪ Increased cost that results from tight management of wellfield operation needed to limit oxygen and nitrogen intrusion into LFG	Requires extensive and potentially expensive LFG processing

The costs presented in Table 4-5 were developed using U.S.EPA's LMOP LFGCost V2.3 model, which estimates the installed LFGE system costs using data from LFG projects in the United States. Analyses performed using LFGCost are considered preliminary and should be used for guidance only. The uncertainty of these costs estimates is +/- 30 to 50 percent. A detailed final feasibility assessment should be conducted by qualified LFG professionals before preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from an LFGE project. Furthermore, a project developer should also consider additional cost uncertainties unique to other geographic boundaries because these data represent costs from United States projects. Costs presented here may vary by country as a result of import fees, taxes, labor, materials, permitting requirements and regulations. The costs shown below do not include the costs for gas collection and flaring systems.

During the first year of operation, annual operating costs include electricity to operate compression and separator systems as well as routine O&M costs on LFG delivery and energy generation equipment. Annual operating costs can escalate based on project-specific factors such as electricity rates, local conditions and labor costs.

Table 4-5. Typical Capital and Annual Costs for Landfill Gas Projects

Technology	Capital Costs (2012 USD)		Annual Costs (2013 USD)	
Direct-Use Medium Pipeline Quality				
Direct Use — **Sizing (m^3/hr):**	**340**	**1,020**	**340**	**1,020**
Skid-mounted Filter, Compressor and Dehydration Unit	$848,000	$983,000	$58,000	$85,000
Pipeline to Convey Gas to Project Boundary[32]	$1,717,000	$1,717,000		
Total Capital Costs Including Cost Contingency	$2,565,000	$2,700,000		
Additional Costs for Retrofitting Boilers				
Pipeline Delivery from End User's Property Boundary to Boiler[33]	$292,000	$292,000		
Metering Station	$81,000	$81,000		
Boiler Conversion for Seamless Controls	$109,000	$155,000		
Total Capital Costs Including Cost Contingency	$3,047,000	$3,228,000		
Electricity				
CHP - Engine[34] — **Sizing (MW Capacity):**	**1**	**3**	**1**	**3**
Gas Compression/Treatment, Engine/Generator, Site Work, Housings and Heat Recovery	$1,985,000	$5,923,000	$185,000	$552,000
Gas Pipeline[33]	$173,000	$173,000		
Water Pipelines and Circulation Pump[35]	$304,000	$304,000		
Engine-Generator Set[34] — **Sizing (MW Capacity):**	**1**	**3**	**1**	**3**
Gas Compression/Treatment, Engine/Generator, Site Work, and Housings	$1,665,000	$4,995,000	$184,000	$553,000
Turbine[34] — **Sizing (MW Capacity):**	**3**	**5**	**3**	**5**
Gas Compression/Treatment, Turbine/Generator, Site Work, and Housings	$6,340,000	$9,496,000	$398,000	$664,000
Direct-Use High Pipeline Quality				
Pipeline Injection — **Sizing (m^3/hr):**	**1,020**	**3,400**	**1,020**	**3,400**
Gas Compressor, Separators, and Dryers for Pipeline Quality Gas	$4,094,000	$8,741,000	$266,000	$886,000
Pipeline to Convey Gas to Project Site[32]	$1,717,000	$1,717,000		
Total Capital Costs Including Cost Contingency	$5,811,000	$10,458,000		

Best Practices for Utilizing LFGE Technologies

The overall feasibility of an LFGE project for a particular landfill depends on numerous technical considerations, such as waste composition and volume, quality and quantity of LFG, and availability and location of a suitable end user. Understanding, evaluating and selecting the appropriate LFGE utilization technologies is essential for the overall feasibility and success of LFGE projects. Proven and emerging technologies offer practical solutions to effectively implement LFGE projects for direct-use and electricity generation, including the treatment of LFG to remove moisture, particulates and other impurities.

[32] Pipelines to convey LFG to project sites were assumed to be 5 miles and exclude pipelines inside the facility.
[33] LFG pipelines inside the property boundary and within the facility were assumed to be 0.5 mile.
[34] Estimates are not provided for electrical interconnect equipment costs because they vary by location.
[35] Water pipelines were assumed to be 0.5 mile.

CHAPTER 5

Market Drivers for LFGE Projects

A robust LFGE market can support a range of national and local government goals, including local, sustainable economic development; reduction of GHG emissions; domestic energy security; and mitigation of adverse environmental impacts of landfills, such as local air quality, odor and ground water contamination.[1] LFGE projects can also serve as a hedge against high prices of imported energy and can also increase energy reliability by providing baseload power to the electricity transmission grid, which increases the availability of power.

The viability of the LFGE sector is a direct result of demand for the resulting renewable energy and the cost-competitiveness of the energy as compared with the alternatives. Other policy and market factors can have an important impact on the financial viability of LFGE projects. These factors include trading markets for emerging commodities such as carbon credits and renewable energy credits, as well as a range of financial mechanisms that can, especially in combination, improve the financial return of an LFGE project investment.

This chapter provides an overview of the range of policy and financing mechanisms that are relevant to the creation of a viable LFGE market. The first section presents policies that apply to the major types of uses of gas from the LFGE projects, and the remaining sections address policies and financing mechanisms that can be designed to apply to some or all of the uses. The chapter is intended to assist stakeholders to understand key market issues as they relate to the financing of LFGE projects.

5.1 End-Use Drivers of Demand for LFGE

The primary types of demand for LFGE are examined here: electricity generation, direct use, natural gas pipeline injection and vehicle fuel. In each section, the key factors that incentivize each type of use are summarized.

Electricity Generation

LFGE projects can produce electricity for export to the electricity transmission network (the “grid”); therefore, utility policies can have a profound impact on the financial viability of an LFGE project. Well-designed utility policies can provide greater market certainty to LFGE projects, thus improving the ability to obtain financing.

Interconnection Standards specify the technical and procedural process used to connect electricity generating systems to the electrical grid. LFGE developers should investigate interconnection standards at the outset of a project and consider how the requirements affect the technical and financial viability of the project. Grid interconnection can be a significant issue in evaluating the feasibility of an LFGE project.

Interconnection standards include the technical and contractual arrangements required of system owners and utilities. Public utility commissions or other authorities typically establish standards for interconnection to the electrical distribution grid and standards for interconnection at the high voltage electricity transmission level.

[1] International Energy Agency. 2009. “*Turning a liability into an asset: The importance of policy in fostering landfill gas use worldwide*.”

Example: Favorable Interconnection Standards in the State of Iowa, U.S.

As with recent interconnection regulation adoptions in many other U.S. states, Iowa standards set four levels of review for interconnection requests. A project must meet all of the requirements of a given classification to be eligible for that level of expedited review. The level of review required is generally based on system capacity, whether system components are certified by a nationally recognized testing laboratory, and whether the system is connected to a radial distribution circuit or to an area network. The basic definitions for each tier are as follows:[2]

Tier 1: Laboratory-certified, inverter-based systems with a capacity rating of 10 kilowatts (kW) or less.

Tier 2: Laboratory-certified systems with a capacity rating of 2 megawatts (MW) or less, connected to a radial distribution network or a spot network serving one customer.

Tier 3: Laboratory-certified, inverter-based systems with a capacity rating of 50 kW or less that are connected to an area network and that will not export power; or laboratory-certified, non-exporting systems connected to a radial distribution circuit where the aggregate total of all generator nameplate capacity is no more than 10 MW (including the distributed generator applicant).

Tier 4: Systems with a capacity of 10 MW or less that do not meet the criteria for inclusion in a lower tier, including all systems using non-laboratory-certified components and those that require additional construction by the utility accommodate the facility.

Feed-in Tariffs (FiT) provide a regulatory approach that improves the financial viability of renewable energy projects, such as LFGE projects. FiTs require electricity transmission and supply companies to accept electricity from renewable energy projects when it is offered for sale. Under a FiT scenario, electric utilities are obligated to purchase, and in some cases pay a premium price for, the electricity generated from the LFGE project. As a result, the FiT approach assures project developers that there will be a market for the electricity produced by a LFGE project. FiT programs may also require electricity supply companies to enter into long-term power purchase agreements (PPA) with renewable energy providers, which improves investor confidence and lowers the cost of capital for investments in qualifying projects.

National FiT policies have been enacted in 45 countries, including in Europe, South America, North America, Southeast Asia, Central Asia, the

Example: Feed-In Tariff – Thailand[3]

In 2007, and modified in 2009, the government of Thailand enacted a feed-in tariff that provides an "adder" paid on top of utility avoided costs, which is differentiated by technology type and generator size, and guaranteed for 7 to 10 years. Solar receives the highest, 8 baht/kilowatt hour (kWh) (about US$0.27/kWh). Large biomass projects receive the lowest at 0.3 baht/kWh (about US$0.01/kWh). Additional per-kWh subsidies are provided for projects that offset diesel use in remote areas. Under the FiT program, as of March 2010, 1,364 MW of private sector renewable energy was online with an additional 4104 MW in the pipeline with signed PPAs. Biomass makes up the bulk of this capacity: 1,292 MW (on line) and 2,119 MW (PPA only).

[2] Iowa Administrative Code. Chapter 45: Electronic Interconnection of Distributed Generation Facilities. https://www.legis.iowa.gov/DOCS/ACO/IAC/LINC/03-21-2012.Chapter.199.45.pdf.

[3] "Feed-in premium for renewable power." Organisation for Economic Co-operation and Development, International Energy Agency. http://www.iea.org/textbase/pm/Default.aspx?mode=re&id=4410&action=detail.

Middle East and Australia. They have also been implemented at the sub-national level in many countries.[4]

Net Metering allows LFGE project operators to offset their electrical use with the electricity generated on-site. As a result, the total amount of electricity supplied to the site is reduced, yielding a lower "net" amount of electricity provided by the power company. The operator pays for this "net" amount of power supplied. In some cases, on-site generation may exceed on-site electricity needs. Net metering provisions have emerged to allow operators to sell their excess electricity to the local power company and receive credit for the amount of electricity provided back to the electrical grid. In these cases, the excess on-site electricity is sent back to the power company either through a second meter for the site, or through a single bi-directional meter. The approach allows the LFGE project to generate and use electricity on-site while maintaining access to grid electricity, and creates a source of revenue for the LFGE project through the sale of excess electricity. Net metering exists at the national level in about 13 countries.[5]

Direct Use

The gas produced at a landfill typically has half the calorific value of natural gas energy sources in the market. As discussed in Chapter 4, while not well-suited for all uses, LFG is less expensive and therefore may be more desirable for those situations that do not require high energy density from the fuel source. In "direct use" applications, the distribution of gas from the landfill to the buyer usually occurs through a dedicated pipeline. LFG can be used to fuel boilers, dryers, kilns, greenhouses and other thermal applications. Industries engaged in direct use of LFG include automobile manufacturing, chemical production, food processing, pharmaceutical, cement and brick manufacturing, wastewater treatment, consumer electronics and products, and prisons and hospitals.

✔ Example: Târgu Mures District Energy in Romania

A 6.5-km landfill gas pipeline transports landfill gas from the Târgu Mures Landfill to the city's four district heating plants.

✔ Example: Vancouver Landfill

Since 1990, an active LFG collection system has operated at the Vancouver Landfill, which is owned and operated by the City of Vancouver in Canada. In 2003, the City of Vancouver expanded the existing collection system, allowing Maxim Power Corporation to pipe LFG to CanAgro Greenhouses; the gas is burned to generate 5.55 MW of electricity for sale to B.C. Hydro and 100,000 GJ/year of heat for sale to CanAgro. The project recovers approximately 500,000 GJ/year of energy. The city will receive revenues of approximately $400,000 per year for the duration of the 20-year contract period.

The key issue that is common to these direct uses is the clean, renewable nature of LFG, which is typically displacing the use of more polluting, and perhaps non-renewable forms of energy. Therefore, a wide variety of renewable energy incentive programs exist at many levels of government that can reduce the costs of project implementation. These programs may take the form of bonds, low interest loans, grants, and a range of tax incentives, each of which is explained further in Section 5.3. For example, in Oregon, U.S., the state's Department of Energy has offered state tax credits and loans such as the State Energy Loan Program since 1981, providing

[4] "Feed-in Tariff." Renewable Energy Policy Network for the 21st Century. http://www.ren21.net/RenewablesPolicy/OverviewonPolicyInstruments/RegulatoryPolicies/FeedinTariff/tabid/5628/Default.aspx.

[5] "Net Metering." Renewable Energy Policy Network for the 21st Century. http://www.ren21.net/RenewablesPolicy/OverviewonPolicyInstruments/RegulatoryPolicies/NetMetereing/tabid/5648/Default.aspx.

loans with favorable terms to renewable energy projects. Since 1984, this program has provided $454 million in support.

Natural Gas Pipeline Injection

Processing LFG to produce pipeline-quality gas requires removal of CO_2 and other impurities. The main obstacles to supplying LFG into the natural gas distribution grid are typically the cost of upgrading the gas and a lack of standards concerning gas quality requirements, injection and measurement procedures. Clear guidelines and regulations are needed to promote investments in upgrading LFG, and standardized procedures help to reduce the time and cost required to access the pipeline network. Other factors that affect the sale of pipeline-quality LFG include the type of pipeline (transmission or distribution) and the structure of relevant energy policies. The primary advantage to injecting LFG into the natural gas grid is the ability to reach a larger market. In the European market, this access was updated in a 2009 EU directive that provides for "non-discriminatory access" to the natural gas transmission network, provided that technical and safety standards are met.[6]

EU Renewable Interconnect Directive[7]

- Article 16 (7): Member States shall ensure that charging of transmission and distribution tariffs does not discriminate against electricity from renewable sources, in particular in peripheral regions. Member States shall ensure that charging of transmission and distribution tariffs does not discriminate against gas from renewable sources.

Example: Biogas Injection into the Natural Gas Distribution Grid[8]

In the Santiago Norte landfill in Chile, biogas will be treated to meet the sales specifications of Metrogas S.A. in an upgrading facility, where most of the non-methane gases will be removed before the biogas is injected to the distribution grid. Project estimates are that an annual average of 70 million cubic meters of biogas will be injected into the distribution grid, equivalent to an average of 1,238 terajoules per year in the first 7-year crediting period, avoiding the consumption of an average of 37 million cubic meters of natural gas per year. The gas will be used in homes, businesses and vehicles. The emission reductions estimated for the first 7-year crediting period are more than 420,000 tonnes of carbon dioxide equivalent, an average of 60,969 tCO_2e per year.

Vehicle Fuel

Landfill gas can be treated to produce either compressed natural gas (CNG) or liquid natural gas (LNG), each of which can be used as vehicle fuel. A common option for the use of LFG-produced CNG or LNG is to fuel a fleet of local vehicles such as those operating at the landfill or community-wide vehicle fleets such as garbage trucks or utility service vehicles. According to the European Commission, 19 percent of the total GHG emissions and 28 percent of the CO_2 emissions in the EU can be attributed to the transport sector, with road transport accounting for more than 90 percent of total EU transport-related

[6] Official Journal of the European Union. 2009. *DIRECTIVE 2009/73/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC.*

[7] Official Journal of the European Union. 2009. *DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009*, Article 16.

[8] "Metrogas – Biogas injection to the natural gas distribution grid." United Nations Framework Convention on Climate Change. Clean Development Mechanism, Project Design Document Form. Section A.2, p. 2.

emissions. Between 1990 and 2005, transport-related emissions increased even as total EU emissions declined following the growth in both passenger (28 percent) and freight (62 percent) transport. As a result, the EU views the use of renewable natural gas, such as LFG, for vehicle fuel as essential for achieving its emission reduction goals.[9]

A low carbon fuels standard (LCFS) can promote the use of LFG fuels in vehicles because of the very low GHG emissions associated with the entire lifecycle of landfill gas CNG and LNG.[11] In the U.S., California is the first state to have adopted an LCFS, one of several requirements of the state's Global Warming Solutions Act of 2006. The California LCFS requires that at least a 10 percent reduction in carbon intensity be achieved from California's use of transportation fuel by 2020; the calculation of carbon intensity includes the complete life-cycle of production, transport, distribution and use of the fuel. The program includes credit trading to reduce the average cost of compliance. Although the program is being challenged in the judicial system, the state is proceeding with its implementation.

The European Green Cars Initiative[10]

To help reduce GHG emissions from the transport sector, the European Green Cars Initiative encourages three categories of action:

- Research and Development, mainly through grants for research on greening road transport. Budget: € 1 billion, of which € 500 million from the European Commission, matched by € 500 million from industry and Member States
- Support to industrial innovation through European Investment Bank loans; the budget is € 4 billion per year (in addition to existing loans)
- Demand side measures and public procurement, such as reduction of circulation and registration taxes for low-CO_2 cars

Example: Use of LFG as an Alternative Fuel for the Urban Bus Fleet in Linköping, Sweden[12]

In the early 1990s, the City of Linköping, Sweden, was converting the city's bus fleet to an alternative fuel to reduce the local pollution from diesel buses. Natural gas was an alternative that was considered. The City of Linköping decided to use locally produced biogas as fuel in the urban bus fleet. The Linköping biogas plant has made it possible for the City of Linköping to decrease the CO_2-emissions from urban transport by 9,000 tons per year and also to decrease the local emissions of dust, sulfur and nitrogen oxides.

5.2 Trading Markets

Increasing concerns about climate change and the emergence of trading systems for carbon and renewable energy provide an important source of demand for LFG because LFG constitutes a renewable source of natural gas that can displace non-renewable fossil fuel sources of natural gas. These markets represent an additional source of revenue for LFGE projects that can make them more financially attractive to implement.

9 Ibid.
10 "Developing greener road transport." European Commission. http://ec.europa.eu/research/industrial_technologies/developing-greener-road-transport_en.html.
11 Argonne National Laboratory. 2010. *Well-to-Wheels Analysis of Landfill Gas-Based Pathways and Their Addition to the GREET Model*. http://www.transportation.anl.gov/pdfs/TA/632.PDF.
12 "100% Biogas for Urban Transport in Linköping, Sweden: Biogas in Buses, Cars and Trains." Biogas in the Society. http://www.iea-biogas.net/_download/linkoping_final.pdf.

Carbon Trading

Joint Implementation and **Clean Development Mechanism** reductions in methane emissions can generate additional revenue for an LFGE project when the reductions meet the requirements for creating carbon offsets, such as those that can be created under the "flexibility mechanisms" of the Kyoto Protocol. The mechanism known as "joint implementation," defined in Article 6 of the Kyoto Protocol, allows a country with an emission reduction or limitation commitment under the Kyoto Protocol (an Annex B "Party;" see Table 5-1) to buy emission reduction units (ERUs) from an emission-reduction or emission removal project in another Annex B country, which can be counted toward meeting the Kyoto target of the purchasing country.

Table 5-1. Kyoto Protocol Annex B Parties[13]

Country	Target (1990** - 2008/2012)
EU-15*, Bulgaria, Czech Republic, Estonia, Latvia, Liechtenstein, Lithuania, Monaco, Romania, Slovakia, Slovenia, Switzerland	-8%
US***	-7%
Canada, Hungary, Japan, Poland	-6%
Croatia	-5%
New Zealand, Russian Federation, Ukraine	0
Norway	+1%
Australia	+8%
Iceland	+10%

* The 15 States who were EU members in 1997 when the Kyoto Protocol was adopted, took on that 8 percent target that will be redistributed among themselves, taking advantage of a scheme under the Protocol known as a "bubble," whereby countries have different individual targets, but when combined, make an overall target for that group of countries. The EU has already reached agreement on how its targets will be redistributed.

** Some EITs have a baseline other than 1990.

*** The U.S. has indicated its intention not to ratify the Kyoto Protocol.

Note: Although they are listed in the Convention's Annex I, Belarus and Turkey are not included in the Protocol's Annex B, as they were not Parties to the convention when the protocol was adopted.

Joint implementation offers the ERU buyer country a flexible and cost-efficient means of fulfilling a portion of its Kyoto commitments, while the ERU seller country benefits from the foreign investment and technology transfer associated with the project that creates the ERUs. As of October 2011, 33 LFGE projects were registered with ERUs within the JI mechanisms.[14]

Internationally, the role of CDM has been central to providing additional financial revenue to methane capture and destruction projects at landfills. As defined in Article 12 of the Kyoto Protocol, CDM allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project (such as LFGE) in developing countries (non-Annex B countries). These emission reduction projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, which can be counted toward meeting Kyoto targets.[15] These reductions allow the Annex B Party countries to meet their obligations through the use of CERs from the implementation of CDM emission reduction projects in developing countries.

[13] "Countries included in Annex B to the Kyoto Protocol and their emissions targets." United Nations. Framework Convention on Climate Change. Kyoto Protocol: Targets. http://unfccc.int/kyoto_protocol/items/3145.php.

[14] "JI projects." UNEP Risoe Centre. http://cdmpipeline.org/ji-projects.htm.

[15] "Clean Development Mechanism (CDM)." United Nations. Framework Convention on Climate Change. http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php.

When evaluating LFGE projects, the potential revenue from CERs should be taken into account because it may make a project viable or profitable.

CER revenue that makes an LFGE project viable may help to satisfy CDM requirements for "additionality," in which additionality refers to the "additional" CERs that would not be achieved without the LFGE project. As of October 2011, there were 193 LFGE projects that had registered within the CDM mechanism.[16]

Determining Additionality

The United Nations Framework Convention on Climate Change's (UNFCCC) Tool for the Demonstration and Assessment of Additionality provides information about how to determine whether a proposed project meets the additionality requirements of the CDM. Related information can be found at http://cdm.unfccc.int/Reference/tools/.

Other credit trading programs, including mandatory and voluntary programs, are also available, such as the EU Emissions Trading Scheme begun in 2003 and the New Zealand Emission Trading Scheme, which was the first mandatory, economy-wide scheme outside Europe. Australia has adopted a carbon tax law for energy-intensive industries that includes emission trading beginning in 2015.[17] China has announced emission trading programs for key cities and provinces in 2013, with the expectation of subsequent expansion to the national level.[18] At the sub-national levels, the State of California in the U.S. is implementing the components of its economy-wide carbon cap-and-trade program, and is working to link its state program with corresponding programs in the Canadian province of Quebec.[19] Voluntary markets also exist such as Japan's Voluntary Emission Trading Scheme (JVETS),[20] the Verified Carbon Standard (VCS) and the Climate Action Reserve (CAR), as does over-the-counter (OTC) trading of carbon derivatives. Alternative market instruments are being considered or are emerging in countries such as Brazil, China, India, Mexico and the Republic of Korea.

Renewable Energy Markets

Markets for renewable energy are driven by requirements on electricity utilities to produce or procure a specified amount of their overall electricity supply from renewable energy sources such as LFGE projects. Renewable energy requirements are referred to differently depending on the country; for example, in the United States they are typically called a Renewable Electricity Standard (RES), in the United Kingdom they are called the Renewables Obligation, and in the EU they are referred to as renewable or quota obligations. Renewable energy requirements mandate that electricity providers document the type of fuel that was used to generate the electricity purchased (or created) by the provider and require that a minimum portion of electricity be produced from renewable fuel sources. Countries will often establish a schedule for phasing in renewable energy requirements that increase the percentages of renewable energy used over time. Such requirements may also include "set-asides" or "carve-outs" that

✔ Example: Renewable Obligations

Renewable obligations have been introduced in many countries, including Belgium, India, Italy, Sweden, UK, Poland and Romania.

[16] "CDM projects grouped by types." UNEP Risoe Centre. http://cdmpipeline.org/cdm-projects-type.htm.
[17] "Clean energy legislation." Australian Government. Department of Climate Change and Energy Efficiency. http://www.climatechange.gov.au/en/government/clean-energy-future/legislation.aspx.
[18] "China to pilot carbon trading scheme: NDRC." China Daily. http://www.chinadaily.com.cn/bizchina/2011-11/23/content_14145909.htm.
[19] "Amendments to the California Cap on Greenhouse Gas Emissions and Market-Based Compliance Mechanisms to Allow for the Use of Compliance Instruments Issued by Linked Jurisdictions." Discussion Draft. California Air Resources Board. March 30, 2012. http://www.arb.ca.gov/cc/capandtrade/draftregquebeclink.pdf.
[20] "Japan's Voluntary Emissions Trading Scheme (JVETS)." Office of Market Mechanisms Climate Change Policy Division, Ministry of the Environment, Japan. May 2011. http://www.env.go.jp/en/earth/ets/jvets1105.pdf.

require utilities to use a renewable resource (such as LFG) to meet a specified percentage of their electricity, which is defined in terms of generating capacity or retail electricity sales.

Regulatory approaches are often structured to include a trading system in which renewable energy generators such as LFGE projects earn Renewable Energy Certificates (RECs) for each unit of electricity produced. RECs allow market participants and electricity regulators to track the amount and type of renewable power being bought and sold. RECs also financially reward eligible renewable energy producers because RECS can be sold by the power producer to the electricity utility companies (power provider). Utility companies that purchase the RECs then submit the certificates to a regulatory body to comply with the company's obligations under the renewable energy regulation. In this way, a renewable energy regulation can provide regulated entities with additional compliance flexibility through the use of a market to reduce compliance costs. At least 13 countries have renewable energy requirements in place.

European Union Commitments[21]

- Article 16 (9): Where relevant, Member States shall assess the need to extend existing gas network infrastructure to facilitate integration of gas from renewable sources.
- Article 16 (10): Where relevant, Member States shall require transmission system operators and distribution system operators in their territory to publish technical rules in line with Article 6 of Directive 2003/55/EC of the European Parliament and of the Council of 26 June 2003 concerning the common rules for the internal market in natural gas, in particular regarding network connection rules that include gas quality, gas odoration and gas pressure requirements. Member States shall also require transmission and distribution system operators to publish the connection tariffs to connect renewable gas sources based on transparent and non-discriminatory criteria.

Renewable Energy Regulations

Regulations may apply a multiplier to each unit of electricity produced by a specified technology (such as LFGE) to support specific renewable energy technologies. For example, an LFGE multiplier of five provides the LFGE project with five certificates for each unit of electricity produced with LFGE. These multipliers may be designed to direct revenue, investment and job creation to a particular type of renewable energy or create "grid parity" by making renewable energy competitive with traditional sources (fossil fuel-based). Regulations may also impose penalties on energy providers that do not meet renewable energy obligations, cap the cost of procuring renewable energy, or suspend the requirement of procuring renewable energy if the cost of meeting the obligations becomes too high.

5.3 Financial Mechanisms

In addition to establishing regulatory requirements, government energy policy can be designed to encourage various energy goals. Energy policy at many levels of government can target and promote LFGE by providing financial incentives to promote the development of landfill gas energy resources. The specifics of these approaches can be very different, and may change over time, because government policy and priorities differ among and within countries. Therefore, each measure must be carefully reviewed for the specific provisions that must be satisfied for projects to qualify, and for provisions that may limit or alter the annual financial benefit over time, including possible expiration dates or termination provisions.

[21] Official Journal of the European Union. 2009. *DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009*, Article 16.

Tax Incentives

Governments are uniquely positioned to affect the financial viability of a project through the availability of tax incentives. These incentives can be designed to reduce the tax burden of projects in proportion to activities such as capital expenditures or productive output. For example, at the federal level, the United States has programs such as the renewable electricity production tax credit (PTC), and the business energy investment tax credit (ITC).

Public-Private Partnerships

The term "public-private partnerships" (PPP) refers to arrangements between the public and private sectors that allow a portion of the services or works that traditionally have been the responsibilities of government to be provided by the private sector, with clear agreement on the division of responsibility, revenues and risk for delivery of infrastructure and or services.

Public-private partnerships include a range of approaches for including the expertise or capital of the private sector. For example, public services that have traditionally been delivered by government entities can be contracted to the private sector. Alternatively, services may be publicly administered with the private sector involved in financing, constructing, operating and possibly taking ownership of an asset.

Public-Private Partnerships

The Canadian Council for Public-Private Partnerships defines public-private partnerships as follows:[22]

A cooperative venture between the public and private sectors, built on the expertise of each partner, which best meets clearly defined public needs through the appropriate allocation of resources, risks and rewards.

Example: Public-Private Partnership

The International Finance Corporation of the World Bank is advising the Government of Kosovo on a public-private partnership to rehabilitate and operate existing landfills according to environmental best practices and EU landfill directives. The landfills, which are operated by the Kosovo Landfill Management Company, are currently treated as dumpsites.[23]

Bond Financing

For government-owned landfills or end users, tax deferred bonds can be used to help finance LFGE projects. These bonds can be a cost-effective method of financing a project since the interest rate is often lower than commercial debt interest rates and can often be structured for long repayment periods. In the United States, a federal bond program was developed for Clean Renewable Energy Bonds (CREBs). This approach provides a tax credit for bond holders rather than interest payments.[24]

Direct Municipal Funding

Direct municipal funding refers to the use of local government operating budgets to fund LFGE projects, eliminating the need to obtain outside financing or partners and potentially avoiding delays caused from their project evaluation needs. However, municipalities may not always have the resources available to

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[22] The Canadian Council for Public-Private Partnerships. http://www.pppcouncil.ca/resources/about-ppp/definitions.html.

[23] International Finance Corporation. *IFC Advisory Services in Public-Private Partnerships: Ongoing transactions in Europe & Central Asia*. http://www1.ifc.org/wps/wcm/connect/5215e1004983917a84c4d6336b93d75f/ActiveMandates_ECA.pdf?MOD=AJPERES&CACHEID=5215e1004983917a84c4d6336b93d75f.

[24] National Renewable Energy Laboratory. 2009. *Fact Sheet Series on Financing Renewable Energy Projects: Financing Public Sector Projects with Clean Renewable Energy Bonds (CREBs).* http://www.nrel.gov/docs/fy10osti/46605.pdf.

finance an entire project and may need to explore alternatives, such as public-private partnerships. In addition, municipalities may be required to seek public approval of government-funded projects, which may result in additional time needed to implement LFGE projects.

Loan Guarantees

Governments, as well as some multinational banks (such as the World Bank Group, The African Development Bank (AfDB), The Asian Development Bank (ADB), The European Bank for Reconstruction and Development (EBRD), and The Inter-American Development Bank Group (IDB)) may provide loan guarantees to smaller lenders for projects that support certain policy goals, such as renewable energy projects. These loan guarantees can be especially helpful for situations when the smaller lenders are not as experienced with renewable energy technologies or financing, or both, and so may not provide favorable terms for promising renewable energy projects. The availability of a loan guarantee can allow loans for these projects to be provided, which supports the commercialization of renewable energy to sustain economic growth, yield environmental benefits and produce a more stable and secure energy supply.

✔ Example: Renewable Energy Loans

The African Development Bank and Eskom, South Africa's largest electric company, signed renewable energy loans worth USD$365M to support South Africa's long-term plans for moving to a lower carbon growth path. Leveraging and accelerating the disbursement of concessional climate financing is essential to achieve economic viability of some of the clean technology solutions.[25]

Equity Financing

An approach to financing LFGE projects involves investors who are willing to fund all or a portion of the project in return for a share of project ownership. Such investors typically use either public or private sources of funds.

Private Equity. Potential investors include developers, equipment vendors, gas suppliers, industrial companies and often investment banks. This option typically has lower transaction costs and may deliver financing more quickly than other options. However, private equity financing can be more expensive than other financing options because of requirements for higher returns. In addition, investors may expect to receive benefits from providing funding, such as service contracts or equipment sales, as well as a portion of the cash flow.

Public Equity. Many governments use a variety of approaches to direct financial support to major projects in other countries if the development of those projects meets the financial, social and political criteria of the investing country. These approaches include financial support from multinational organizations mentioned above, the WB, the AfDB, the ADB, the EBRD, and the IDB, as well as several groups within the United Nations. Furthermore, many countries have agencies that invest in projects directly, rather than, or in addition to supporting the multinational entities. Examples of these "bilateral" institutions include the German Development Bank (KfW), the Canadian International Development Agency (CIDA) and the French Development Agency (AFD).[26]

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[25] "AfDB, Eskom Sign USD365M Renewable Energy Loans." African Development Bank Group. http://www.afdb.org/en/news-and-events/article/afdb-eskom-sign-usd365m-renewable-energy-loans-8385/.

[26] For more information, see: http://www.climatefundsupdate.org/global-trends/global-finance-architecture.

Renewable Energy Investment Forum

The Renewable Energy Investment Forum was formed in 2003 to support collaboration among renewable energy project investors. The forum focuses on projects that reduce or eliminate dependence on fossil petroleum and other high-risk, high-cost technologies. Initial screening criteria for consideration of a candidate project include:

- Proven, off-the-shelf technologies with many years of commercial use in the environment and at the scale intended by the project sponsors.
- Experienced, reputable project sponsors and management teams.
- An asset basis, credit history and above-average credit scores for principals or sponsors.
- Reasonable return given the opportunity, current economy and history.
- The project must have sufficient upside to easily afford debt service, which is usually demonstrated by carefully structured and detailed financial plans for the life of the project.
- Depending on power purchase arrangements, project sponsors must allow for likely changes in energy prices, full equipment maintenance, amortization and labor (operating) costs.

Public Benefit Funds

Public Benefit Funds (PBFs), which are a financial resource created by applying a fee onto customers' utility rates, are another mechanism to support policy objectives (such as developing LFGE projects). Revenue generated by the fee can be used by public institutions and governments to increase the availability of renewable energy, and can result in investment in LFGE projects. PBFs can also be administered by public-benefit corporations that are chartered by a government and designed to support a specified public benefit. A public authority is a type of public-benefit corporation that takes on the role of maintenance of public infrastructure (such as LFGE projects) and may have powers to regulate or maintain public property (such as LFGE equipment). In the United States, PBFs are in place in 30 states and the District of Columbia.[27]

Grants

Grant programs can offer support for a broad range of landfill gas technologies or can focus on promoting a single technology. Grants may be made available to the commercial, industrial, utility, education or government sectors. These programs are often designed to contribute to the cost of eligible LFGE systems or equipment. Alternatively, grants may focus on LFGE research and development, feasibility studies, project demonstrations or support project commercialization. Available grant funds are typically distributed through a competitive process.

[27] U.S. Department of Energy, Energy Efficiency and Renewable Energy. 2010. *Public Benefit Funds: Increasing Renewable Energy & Industrial Energy Efficiency Opportunities*. http://www1.eere.energy.gov/manufacturing/states/pdfs/pbf_factsheet.pdf.

Examples: Renewable Energy Grants

In the United States, a grant program was developed by the Department of Treasury to support investment in renewable energy, allowing a facility owner to receive a one-time grant equal to 30 percent of the construction and installation costs for the facility if the facility is depreciable or amortizable.[28] Other grant opportunities are available in the U.S. through public and private sources.[29]

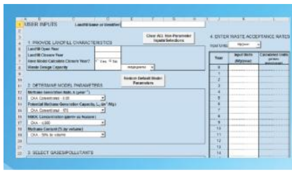
The Bulgarian Energy Efficiency and Renewable Energy Credit Line (BEERECL) provides grants of up to 15 percent of the investment amount required for qualifying renewable energy projects, including biogas.

Best Practices for Understanding Market Drivers for LFGE Projects

It is important that stakeholders recognize and understand how policy and market drivers affect the development of LFGE resources and support the long-term sustainability of LFGE projects. Policy and financing mechanisms are central to assessing the financial viability of LFGE projects. While market drivers and financing mechanisms will vary by country and region, the demand for renewable energy and cost-competitiveness of that energy compared with alternatives should be assessed carefully during the planning stages of an LFGE project to ensure that the most effective combination of revenue opportunities is harnessed.

[28] U.S. Department of the Treasury. Recovery Act. http://www.treasury.gov/initiatives/recovery/Pages/1603.aspx.

[29] U.S. Department of Energy and North Carolina State University. Database of State Incentives for Renewables and Efficiency. Summary Maps. http://www.dsireusa.org/summarymaps/index.cfm?ee=1&RE=1.



CHAPTER 6

Landfill Gas Modeling

When an SWD site owner or project developer wants to consider the technical and economic feasibility of an LFGE project, the first step is to estimate the volume of LFG (specifically methane) that can be collected. In many cases, no active collection system is installed and no LFG flow data exist to indicate an achievable collection rate. In cases where an active LFG collection system exists, flow and methane measurements provide historical LFG (and methane) volumes, but do not provide information on future LFG collection potential. For these reasons, a model to estimate LFG collection is an essential tool for planning an LFG flaring or energy project.

This chapter provides an understanding of selected publicly available LFG models, describes how these models are applied to estimate methane collection from SWD sites, and identifies considerations for their use. Topics covered include the following:

1. An overview of LFG generation, emissions and collection
2. Factors influencing LFG generation
3. Publicly available LFG models
4. Data needed to model LFG generation and collection
5. Estimating collection efficiency
6. LFG model uncertainty and performance.

> **Lessons Learned**
>
> Many LFGE projects in developing countries have failed to collect the volume of LFG anticipated at the beginning of the project. In many cases, the project design reflected inflated expectations based on inappropriate application of an LFG model.[1] For example, use of U.S.-based LFG models, which are designed for sanitary landfills in the United States, cannot accurately account for landfills in developing countries with vastly different waste characteristics and site conditions.
>
> In the last several years, LFG models better suited for estimating the volume of LFG in developing countries have become publicly available; these models provide more realistic expectations of the potential for landfill methane recovery.

Costs associated with conducting LFG modeling are not presented because modeling depends on project-specific factors, which can vary significantly among countries.

6.1 LFG Generation, Emissions and Collection

An introduction to LFG generation models requires an understanding of the different pathways for generated LFG and how models have been used for estimating LFG generation and collection. A full accounting of the volume of LFG generated requires the identification of all of the terms on the right side of the following equation:

Generation = Collected LFG + Uncollected LFG Emitted through Cover + Methane Oxidation in Cover Soils + Lateral Migration + Change in LFG Storage

Collected LFG is the only term that can be accurately measured. The other terms are generally unknown. Therefore, LFG generation models cannot be fully validated with measured LFG collection data because the unmeasured parameters introduce potential error into the calculations.

[1] SCS Engineers. 2009. *Methane Emission Reductions Achieved by Landfill Gas Projects in Developing Countries*.

Evaluating Model Performance

Model performance can be evaluated at sites with active gas collection systems if data are available for LFG flow and methane concentration. However, these evaluations should be conducted at sites that have an extensive gas collection system and collect a high percentage of the generated LFG.

Modeling LFG Generation

LFG generation models were initially designed to estimate air emissions from landfills. The U.S. EPA's Landfill Gas Emissions Model (LandGEM)[2] was designed to serve as a tool for estimating emissions of various LFG constituents from U.S. landfills. Another landfill methane emissions model designed for worldwide applications is the Intergovernmental Panel on Climate Change (IPCC) Model.[3] These LFG generation models typically ignore lateral migration and change in storage, and either ignore methane oxidation in cover soils or assign it to a default value (for example, 10 percent), before subtracting recovery from modeled generation to calculate emissions. For example, LandGEM does not include an oxidation calculation, and the IPCC Model assigns default values for methane oxidation equal to 10 percent of uncollected LFG for managed sites with oxidizing soil covers and 0 percent for all other sites. Recent field studies have provided evidence of oxidation rates much higher than 10 percent at sites with good soil cover and efficiently operating gas collection systems. This recent research is reflected in a new landfill methane emissions model released in 2011 that provides a realistic accounting of methane oxidation, the California Landfill Methane Inventory Model (CALMIM).[4] CALMIM does not model LFG generation; instead, it models the processes that control emissions, including cover types and extent, the fraction of area with LFG collection, and the seasonal methane oxidation rate.

Additional Model Resources

Other models that estimate landfill methane emissions not discussed in this chapter include the U.S. EPA's Waste Reduction Model (WARM) and the British Environment Agency's GasSim2.5.

Modeling LFG Collection

LFG collection can be estimated using models by multiplying LFG generation projections by the percent "collection efficiency," a measure of the actual or expected ability of the gas collection system to collect generated LFG. For sites without an operating gas collection system, collection efficiency can be assigned an assumed default value (for example, 75 percent for U.S. landfills planning a comprehensive collection system), or a value estimated based on site characteristics and proposed gas collection system design (if available). Collection efficiency at sites with operating gas collection systems can be assigned a value that is back-calculated by dividing actual measured LFG collection by modeled LFG generation. Otherwise, it can be estimated independently of models based on an evaluation of site characteristics and gas collection system coverage and operations.[5] The U.S. EPA GHG Reporting Program methodology for estimating landfill methane emissions provides instructions for estimating collection efficiency based

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[2] U.S. EPA. May 2005. *Landfill Gas Emissions Model (LandGEM), Version 3.02.* EPA 600-R-05-047. http://www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf and http://www.epa.gov/ttn/catc/products.html#software.

[3] IPCC. 2006. *IPCC Guidelines for National Greenhouse Gas Inventories.* Volume 5, Chapter 3. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf.

[4] See for example, Bogner et al. 2010. *Improved Understanding of Seasonal Methane Oxidation In Landfill Cover Soils: An Important Component of a New IPCC Tier IV Greenhouse Gas (GHG) Inventory Methodology*. SWANA 33rd Annual LFG Symposium. 8-11 March 2011, San Diego, CA.

[5] SCS Engineers. January 2009. *Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills*. http://www.scsengineers.com/Papers/Sullivan_SWICS_White_Paper_Version_2.2_Final.pdf.

on cover type and fraction of waste area with wells.[6] Country-specific LFG models developed by GMI include methods for estimating collection efficiency and are discussed in more detail in a later section. Figure 6-1 illustrates an example of calculating the collection efficiency for an LFG project that installed a gas collection system in 2003 and that will stop accepting waste in 2011.[7]

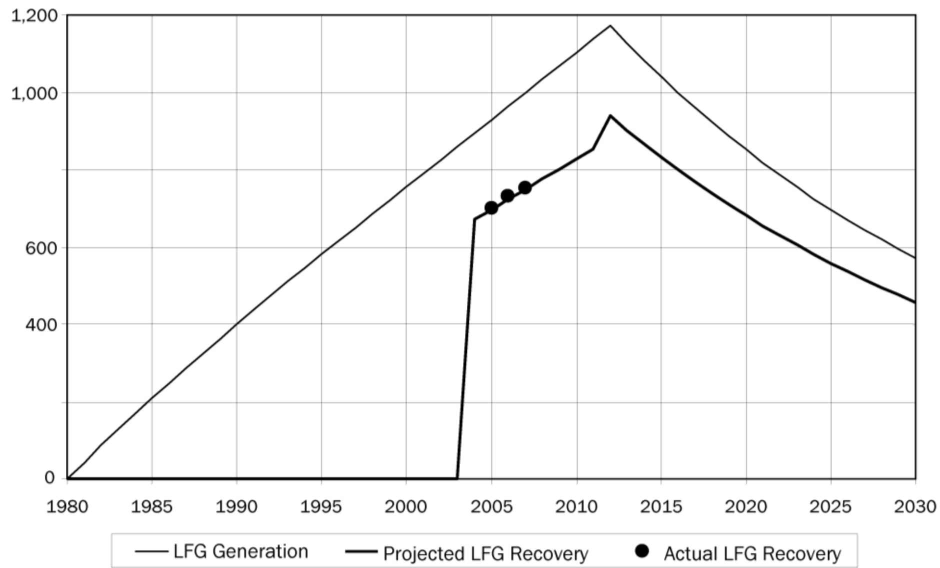

Figure 6-1. Example LFG Generation and Recovery Graph

When LFG generation models are used to estimate LFG collection instead of air emissions, their assumptions can be tested using measured collection data and estimates of collection efficiency. However, collection efficiency estimates can introduce significant error. Collection efficiency is especially difficult to estimate accurately at open dumps or poorly managed SWD sites where site conditions, site management practices, waste composition, and climate can exhibit significant variation and may be distinctly different than at well-operated sanitary landfills.

LFG models need to incorporate the likely impacts of differences in site conditions and these other factors when estimating LFG collection. For example, country-specific LFG models may incorporate in-country data and site characteristics, including waste composition, climate and measured LFG collection from operating projects. These models also may automatically calculate collection efficiency or provide instructions on estimating collection efficiency based on soil cover types and extent, extent of collection system coverage of disposal cells, and other influencing factors.

Estimating LFG collection using LFG models is a critical component of project assessments to evaluate the technical and economic feasibility of a proposed LFG project. The LFG collection projections are used to estimate project design requirements, capital and operating costs, the size of the project that can be supported, and the expected revenues from the sale of emission reduction credits and or energy. In particular, the design parameters of a gas collection system depend heavily on model estimates of LFG collection for the project design and implementation phases, as well as for pre-project planning (project feasibility assessment). A detailed evaluation of future LFG collection by an experienced LFG modeler can indicate system design requirements throughout various phases of the project as it expands into new waste disposal areas.

[6] U.S. EPA Greenhouse Gas Reporting Program. 40 CFR Part 98, subpart HH- Municipal Solid Waste Landfills, http://www.epa.gov/climatechange/emissions/subpart/hh.html.

[7] U.S. EPA. 2010. *LFG Energy Project Development Handbook*. http://www.epa.gov/lmop/publications-tools/handbook.html.

Modeling Requirements for Registering LFG Projects

If an LFG project is being implemented under a certified emissions reduction revenue stream, such as CDM or a JI mechanism, then LFG modeling is required as part of the registration process using a prescribed calculation method or "tool."[8] The project proponent (SWD site owner or project developer) is required to complete a project design document (PDD) for the planned project and the PDD includes projections of CERs achieved through combustion of methane (in the case of LFG flaring projects) and the sale of electricity or thermal energy from LFG (in the case of LFG utilization projects).

6.2 Factors Influencing LFG Generation

A basic knowledge of environmental factors influencing LFG generation is important for understanding LFG modeling. LFG is generated through the action of microorganisms that begin decomposing organic waste within about 3 to 6 months after disposal, if the waste is in an anaerobic state. The rate of LFG generation caused by waste decomposition is sensitive to a number of environmental factors, including moisture, temperature, oxygen and refuse degradability. The effects of each of these variables can be summarized as follows:

- **Moisture** is one of the most important variables influencing LFG generation. LFG generation is known to increase with moisture because higher waste moisture content contributes to an increased rate of waste decay, but the total amount of LFG generated over time ("ultimate yield") may not increase with increases in moisture above a minimum threshold needed to support microorganisms that generate LFG. Moisture conditions can vary widely from desert to tropical sites or even within sites with liquids recirculation. Average annual precipitation is typically used as a surrogate for moisture because moisture within a waste mass is difficult to measure.
- **Temperature** increases generally cause LFG generation to increase up to approximately 57 degrees Celsius (^{o}C). At higher temperatures, the amount of LFG generation decreases, and the higher temperatures indicate aerobic rather than anaerobic decay, which can lead to subsurface fires. While cold air temperatures can penetrate the surface of the waste mass and decrease LFG generation, particularly in small, shallow sites, most of the waste mass of larger sites will be insulated from outside temperatures and warmed by microbial activity. Temperature effects on LFG generation are complex, and temperature profiles within a waste mass are too varied to characterize for LFG modeling, although some models do incorporate ambient air temperatures into their calculations.
- **Oxygen** in air can penetrate a waste mass and inhibit anaerobic microorganisms from producing LFG. A significant portion of the waste mass at shallow sites and sites with limited or no cover may be affected by air infiltration and reduced LFG generation. Gas collection systems also can contribute to enhanced air infiltration, particularly when operated aggressively.
- **Refuse degradability** has an important influence on the amounts and rates of LFG generation. Highly degradable organic materials, such as food waste, will produce LFG rapidly but will be consumed more quickly than less degradable organics, such as paper, which produce LFG slowly but over a longer time. Materials such as wood exhibit little degradation and produce minimal quantities of LFG. Inorganic materials do not produce LFG.[9]

[8] United Nations Framework Convention on Climate Change (UNFCCC) Methodological Tool. "Emissions from solid waste disposal sites." http://cdm.unfccc.int/Reference/tools/index.html.

[9] Pierce, Jeffrey, Les LaFountain and Ray Huitric, SWANA. 2005. *Landfill Gas Generation and Modeling: Manual of Practice (Final Draft)*.

6.3 Publically Available LFG Models

The first and probably most important step in the modeling process is the selection of an appropriate model for LFG project evaluation. This section provides more details on publicly available LFG models, including LandGEM, IPCC and GMI country-specific LFG models. The discussion covers model variables, model calculation methods and considerations for their use in projecting LFG collection from SWD sites. Guidance or accompanying documents for each of these models provide a background on model assumptions and calculations, as well as instructions on model use.

When waste is placed in a site, the rate of waste decomposition and LFG generation are most rapid after waste disposal and gradually declines over decades as organic waste is depleted. Maximum LFG generation normally occurs within the first 2 years after the site stops accepting waste. This pattern of LFG generation over time is incorporated into LFG models typically by applying a first-order exponential decay equation, which assumes that LFG generation is at its peak following a time lag (period prior to methane generation), and then decreases exponentially as the organic fraction of waste is consumed.

LandGEM

LandGEM applies a first-order decay equation to calculate methane generation rates in units of flow (cubic meters [m^3]/year or average cubic feet [ft^3]/minute) or mass (Megagrams [Mg]/year). LandGEM was designed for U.S. regulatory applications but has been used for modeling LFG collection in the U.S. and worldwide. It applies the following first-order exponential equation to estimate methane generation:

$$Q = \sum_{t=1}^{n} \sum_{j=0.1}^{1} k L_0 \left[\frac{M_i}{10} \right] (e^{-kt_{ij}})$$

Where:

	Q	=	maximum expected methane generation flow rate (m^3/yr)
	i	=	1 year time increment
	n	=	(year of the calculation) – (initial year of waste acceptance)
	j	=	0.1 year time increment
	k	=	methane generation rate (1/yr)
	L_0	=	potential methane generation capacity (m^3/Mg)
	M_i	=	mass of solid waste disposed in the i^{th} year (Mg)
	t_{ij}	=	age of the j^{th} section of waste mass M_i disposed in the i^{th} year (decimal years)

The LandGEM equation is used to estimate methane generation for a given year from cumulative waste disposed up through that year. Multi-year projections are developed by varying the projection year, and then re-applying the equation. Total LFG generation is equal to the methane generation rate divided by the volume fraction of methane assumed in the LFG. For example, two times the calculated methane generation if the LFG is assumed to contain 50 percent methane (Q_{LFG} = Q/0.5 = 2Q).

Other than waste disposal rates, the main variables in the first order decay equation are the methane generation rate constant (k), and the potential methane generation capacity (L_0), which are described below:

- **The methane generation rate constant (k)** describes the rate at which refuse decays and produces methane and is related to the half-life of waste based on the following equation: half-life = ln(2)/k. At low k values, methane generation is limited because a relatively small fraction of the deposited waste decays each year and produces LFG. At higher k values, a greater percentage of waste decays and produces LFG each year, resulting in higher methane generation rates. High k values result in rapid increases in LFG generation over time while the site is still receiving waste, but also rapid declines after the site closes because the waste continues decaying rapidly without being replenished. LFG generation can be visualized by a steeply rising curve followed by a steeply declining curve.[10] While several factors influence the k value, it is primarily controlled by waste type (organic waste degradability) and moisture content (estimated based on average annual precipitation).

- **The potential methane generation capacity (L_0)** describes the total amount of methane gas potentially produced by a metric tonne (Mg) of waste as it decays. It depends almost exclusively on the waste composition. A higher cellulose content in refuse results in a higher value of L_0. Although the potential methane generation capacity may never be reached at sites in very dry climates, the L_0 is viewed as being independent of moisture above a certain minimum threshold.

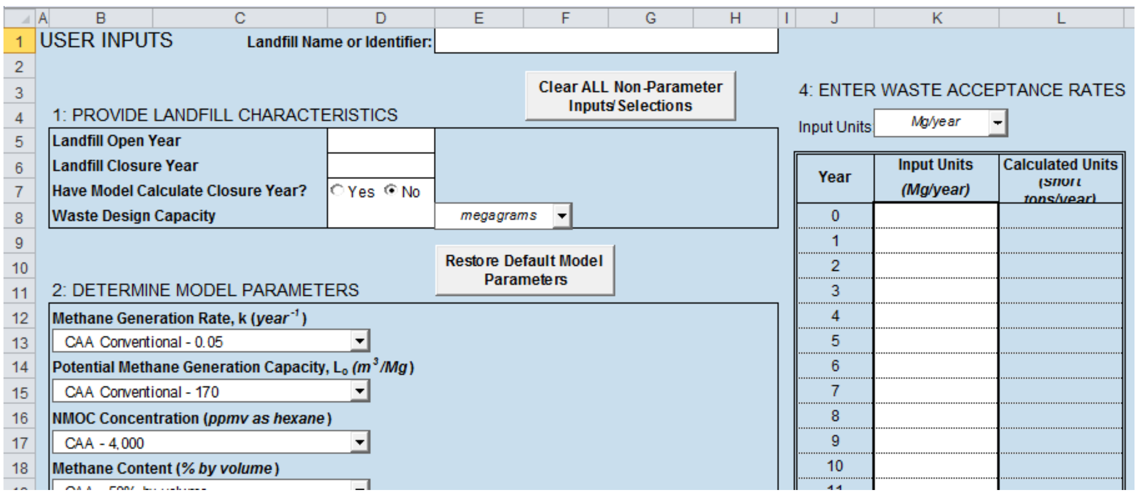

Figure 6-2. LandGEM User Input Sheet

LandGEM Limitations for Modeling Sites Outside of the U.S. In LandGEM's input sheet, model users are provided with alternative default values for the input variables k and L_0, depending on whether the model is being used for U.S. Clean Air Act compliance or other ("inventory") applications, whether the site is in an arid or non-arid ("conventional") climate, and whether the site is designed and managed for accelerated waste decay through liquids recirculation (bioreactor or "wet" conditions) (see Figure 6-2). The default k and L_0 values may be appropriate for modeling LFG generation from U.S. landfills that are characterized by these conditions, but they often are not appropriate when applied to SWD sites that may exhibit very different site conditions and waste composition, which cause dramatically different rates of LFG generation. Because LandGEM was based on data from SWD sites in the U.S., it assumes that the site being modeled is an engineered sanitary landfill. Therefore, it may not be appropriate for unmanaged dump sites where limited soil cover, poor waste compaction, high leachate levels, and other conditions can significantly limit LFG generation and collection. Additionally, LandGEM may not be appropriate for countries with significantly different climates or a different mix of waste types. As discussed below, international LFG models are designed to include adjustments to account for limits to LFG generation and collection caused by conditions at dump sites.

[10] See for example Figure 2-1 in U.S. EPA, 2010, *LFG Energy Project Development Handbook* (http://www.epa.gov/lmop/publications-tools/handbook.html), which shows different LFG generation curves produced by k values of 0.02 and 0.065.

SWD sites in many developing countries not only experience very different climates than in the U.S., but they also receive a very different mix of waste types. For example, typical municipal solid waste (MSW) in the U.S. contains approximately 18 percent food and 22 percent paper.[11] In developing countries, MSW often contains more than 50 percent food waste and less than 15 percent paper. With its higher food waste content, MSW will degrade and produce LFG much more rapidly than U.S. MSW. Therefore, a higher k value than would be used for U.S. SWD sites would be needed to accurately account for the different waste profile, even before any accounting for climate differences. Such higher k values are not provided in LandGEM unless specified by the user.

Example: LandGEM Limitations for Moisture Conditions

The range of default k values in LandGEM for non-bioreactor (arid and conventional) landfills is limited to 0.02 for sites that experience less than 25 inches (635 millimeters [mm]) of precipitation per year and 0.04 or 0.05 for sites that experience higher rainfall amounts. This range of values may reflect the typical range of moisture conditions found in most landfills in the U.S., but most tropical countries have regions where rainfall commonly exceeds 2,000 mm/year and can exceed 4,000 mm/year. LandGEM does not provide any guidance on appropriate k values for such rainy climates.

Additionally, a high percentage of food waste also creates a different pattern of waste decay over time. Because food waste decays more rapidly than other organic materials, it also is depleted more rapidly once waste disposal stops. A waste stream high in food waste will experience a rapid decline in LFG generation after disposal ends because food waste has a very short half-life (as reflected by a high k value). After a few years when the food waste has mostly degraded, only the slower decaying organic materials (such as paper) remain. These materials are less productive at generating LFG and also degrade at a slower rate. Changes in the mix of waste materials that are the primary generators of methane in an SWD site over time that result from varying degradation rates are not accommodated in LandGEM, which assigns a single k value for all wastes. Therefore, the LandGEM model reflects an unchanging "average" waste decay rate. While this limitation may not create a large error for modeling U.S. SWD sites, it can overestimate long-term LFG generation after site closure at sites with high food waste disposal rates. Not only are the default k values assigned in LandGEM not appropriate for modeling the climate and waste conditions experienced in many countries, but the use of a single k value for all wastes is flawed for sites with a high percentage of food waste where average waste degradability (and LFG generation) varies significantly over time.

The IPCC Model

The IPCC Model was released in 2006 and has several features that make it more suitable than LandGEM for assessing SWD sites worldwide, including applying separate first-order decay calculations for different organic waste categories with varying decay rates. The model was developed for countries to estimate methane emissions from waste disposal using regional per capita waste generation rates and population estimates, with deductions for LFG collection and oxidation. Although it was designed for estimating methane generation from entire countries, the IPCC Model can be modified to estimate generation from individual SWD sites. The standard GHG emissions reduction methodology for LFG projects seeking registration under the CDM is derived from the IPCC Model, and it uses the same variables and calculations.[12]

[11] U.S. EPA. November 2008. *Municipal Solid Waste in the United States: 2007 Facts and Figures.* http://www.epa.gov/osw/nonhaz/municipal/pubs/msw07-rpt.pdf.

[12] CDM. *Methodological Tool: Emissions from solid waste disposal sites, Version 06.0.0.* http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-04-v6.0.0.pdf.

Like LandGEM, the IPCC Model uses a first-order decay equation that applies annual waste disposal rates and a waste decay rate variable (k value). The first-order calculations do not include the LandGEM variable L_0, but include other variables that, when combined together, constitute an L_0 equivalent variable, including the fraction of degradable organic carbon (DOC), the fraction of degradable organic carbon that decomposes (DOC_f) and a methane correction factor (MCF).

Unlike LandGEM, the IPCC model includes features that make it appropriate for modeling non-U.S. SWD sites, including the following:

- An allowance for the user to input waste composition data divided into the following categories: food waste, garden, paper, wood and straw, textiles, disposal diapers (“nappies”), sewage sludge, and industrial waste. If no waste composition data are available, the model provides regional default values. The model also assigns different DOC values for each waste type based on the amount of degradable organic carbon.
- The assignment of different k values for different waste types grouped into four categories based on their decay rates. For example, food waste and sewage sludge (category 1) have the highest k values, followed by garden waste, disposable diapers and industrial waste (category 2), paper and textiles (category 3), and finally by wood and straw (category 4), which have the slowest decay rates.
- The option of four different climates based on mean annual temperature, precipitation and (for temperate climates) potential evapotranspiration (PET). The climate categories are wet tropical, wet temperate, dry tropical and dry temperate. The model assigns k values for each of the waste categories based on climate as well as the waste decay rate.
- The inclusion of an MCF discount to account for aerobic (non-methane generating) waste decay at unmanaged disposal sites.

As a result of the features described above, the IPCC Model is currently the best available tool for estimating LFG generation from SWD sites in most countries. However, because it is a global model, it is not precise in its accounting for conditions in individual countries, particularly precipitation and its effects on LFG generation, since only two categories are used.

Limitations of the IPCC Model

While the IPCC Model’s four climate categories represent an improvement over LandGEM’s two climate category approach, limitations exist, including the following:

(1) Temperature has a smaller impact on LFG generation than precipitation and should not be assigned equal weight in assigning climate categories;

(2) PET data are usually not available for most locations and should not be a basis for assigning climate in temperate regions even if they are scientifically more valid;

(3) The 1,000 mm/year precipitation threshold for separating tropical climates into dry vs. wet categories is better than the LandGEM threshold of 635 mm/year (25 inches/year) but is likely too coarse to account for the effects of precipitation across the wide range of values encountered. For example, most areas in Colombia experience more than 1,000 mm/year of precipitation and many areas get more than 2,000 mm/year. Landfills in these areas would be treated the same (identical k values) in the IPCC Model, which implies that there are no noticeable effects from increasing precipitation above 1,000 mm/year.

Country-Specific Models Developed by the Global Methane Initiative

GMI has developed country-specific models that apply the structure of either LandGEM or the IPCC Model, but combine it with detailed information from each country to produce models that more realistically reflect local conditions which impact LFG generation and collection. These models were designed for non-expert users and may be advantageous for estimating LFG collection in each of the specific countries for the following reasons:

Country-Specific Models

- Landfill Gas Emissions Model (LandGEM)
- Central America LFG Model
- China LFG Model
- Colombia LFG Model
- Ecuador LFG Model
- Mexico LFG Model 2.0
- Philippines LFG Model
- Thailand LFG Model
- Ukraine LFG Model

- All eight of the GMI country-specific LFG models were developed after a study of the regional climates and automatically assign k and L_0 variables appropriate for the climate where the SWD site is located.
- Most of the models automatically calculate collection efficiency based on answers to the following factors: overall site conditions (dump site or managed landfill); waste depth; waste compaction practices; size of the tipping area; bottom liner type; percent of disposal area with operating extraction wells; percent of disposal area with daily, intermediate and final cover; and evidence of elevated leachate levels. Models that do not automatically calculate collection efficiency provide guidance on how to estimate collection efficiency.
- GMI models developed for Colombia, Mexico and Ukraine have the following additional features:
  - Default waste composition values based on detailed analysis of waste composition in these countries so that the user is not required to obtain these data. (The Central America Model also has this feature.)
  - Assignment of k values appropriate for the local climates based on a detailed analysis of average precipitation across all regions of these countries and the division of each country into four climate zones that reflect the range of climate conditions.
  - Automatic calculation of waste disposal rates based on the minimum required information (opening and closing years, recent year's annual disposal or waste in place, and growth rate).
  - Adjustments to account for aerobic waste decay (MCF) and past fires, both of which are common at unmanaged SWD sites and can significantly reduce LFG generation. (The models for China, the Philippines and Thailand also have this feature.)
  - Use of the IPCC Model structure and assignment of separate k and L_0 values to four waste groups based on waste degradability. This "multi-phased" first-order decay model approach avoids the single k model problem described previously and recognizes that significant differences in the types of waste disposed require changes to the model structure as well as to the values of the input variables.
  - Allows the user to override the automatic selection of model variables (other than k and L_0 values) with site-specific data. This feature includes methods for adjusting collection efficiency based on measured flow data at sites with operating collection systems.

6.4 Data Needed to Model LFG Generation and Collection

> **Data Collection Methods Vary**
>
> Because data collection methods and data quality can vary widely from country to country, there is no single standardized method that would apply to all cases.

Regardless of the type of LFG model that is used, the validity of the model results will be largely determined by the quality of the data used in the model. As the mathematical modeling saying goes, "garbage in, garbage out." Therefore, care should be taken in scrutinizing the data used to conduct LFG modeling. This section provides general guidance on obtaining and applying data needed for running the GMI and IPCC models, but does not provide detailed instructions on modeling procedures or explanations of model calculations that are covered in their supporting documents. A "best practices" approach to gathering all needed data is discussed, including the general procedure of using multiple data sources to accomplish a single task, such as double-checking historical waste disposal rates against estimated volume of waste in place (see below).

Historical Waste Disposal Estimates

Annual waste disposal rates are critically important model inputs that strongly influence projected LFG generation. When historical disposal records provided for a site are considered, a modeler needs to know their source and reliability. Are the disposal rates based on truck scale records? If so, when were the truck scales installed and how were tonnages for prior years estimated? For periods without actual historical waste tonnage data, past disposal rates can be estimated based on the following information:

- **Waste volume estimates based on records of incoming waste delivery vehicle counts and capacities.** The incoming waste volume estimates require conversion to weights based on the estimate of "as received" waste density. Different waste loads will have significantly varying densities, depending on the waste category (so, for example, construction waste will have a higher density than regular MSW), so some records of the sources of waste also may be required.
- **Site opening year and annual growth in disposal.** The models require assigning a start year, so the actual or estimated site opening date is an essential data item that must be obtained. Because disposal growth rates are related to population growth, they can be estimated or checked using population growth data. At a minimum, the opening year and growth rates need to be coupled with one more piece of information — either the amount of waste in place, or at least one year's disposal estimate — to develop a disposal history.
- **Estimated amount of waste in place.** Waste in place can be roughly calculated using a scaled site drawing showing the size of the waste disposal area and an estimate of the average waste depth. Topographic maps of the site can be used to develop more detailed estimates of waste depth and volume, but a drawing showing base contours is needed to yield a precise estimate since only the surface contours are shown on the map. Once a waste volume is calculated, it needs to be converted to mass using an appropriate "in-place" density factor. This conversion can create error because densities can vary widely depending on site conditions and waste composition, as well as on soil cover volumes (and whether soil is included in the density calculations). Typical in-place waste density for sites in developing countries is about 0.6 to 0.8 Mg/m^3, but densities outside of this range commonly occur based on varying site conditions.

Checking historical waste disposal estimates against the estimated volume and mass of waste in place is a good practice, especially at older sites where disposal records may be uncertain or have missing data.

Future Waste Disposal Estimates

Future waste disposal estimates require, at a minimum, an estimated growth rate and either a site closure date or a total (or remaining) site capacity with a density conversion factor. Completing independent calculations to project the year that the site reaches capacity to validate a site closure date is also recommended. However, a closure year may be set by a permit expiration date or some other reason that can prevent the site from being filled to capacity.

Waste Composition Data

Waste composition strongly influences the amount and timing of waste generation by setting the amounts and relative decay rates of the various degradable organic waste categories. Waste composition studies are relatively common in many countries and are conducted by municipalities or universities to help in developing solid waste planning programs. While waste composition data may not be available for the specific site being modeled, studies providing data from other cities or sites in the country often are available. In such cases, the waste composition data source and the modeling study site should be compared to evaluate whether the data are representative, although in many cases there may be no alternative data.

Another consideration is the need for the waste disposal estimates and composition data to be consistent. For example, a site may receive a high percentage of construction and demolition (C&D) waste that is included in the disposal estimates but not in the waste composition data. (Only regular MSW may have been evaluated in the study.) In such cases, the extra C&D waste tonnages not reflected in the waste composition percentages should be subtracted from the inputs to the model.

Finally, any significant changes to waste composition that are expected in the future should be considered. For example, waste composition could be significantly affected if a large new industrial waste contract is expected or a major organic waste recycling program is planned. Future changes in waste composition can be incorporated directly into the IPCC Model, but the LMOP models require separate model runs to reflect conditions before and after the expected change.

Climate Data

The IPCC and GMI models assign k values according to climate and waste composition. The best source of reliable climate data worldwide is World Climate, which presents processed surface station observations of temperature, precipitation and pressure data from the Global Historical Climatology Network (GHCN). Data are listed by the name of the closest municipality and organized by grouping all climate stations within the same 1 degree longitude by 1 degree latitude on the same web page. Data coverage is not available for many remote regions of the world. Other websites with worldwide climate data include the World Meteorological Organization's World Weather Information Service and Weather Base. Select the closest station to the site being modeled that has the longest climate record. Some sites record on-site precipitation, although the reliability of these data will be unknown and should not be used if they show values that are significantly different from the closest public station.

GHCN Climate Data Set

Produced jointly by the National Climatic Data Center and Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory in the United States, the GHCN is a comprehensive global surface baseline climate data set designed to be used to monitor and detect climate change.

Site Management, the Methane Correction Factor and Fire Impacts

The IPCC Model and several of the GMI models apply a methane correction factor (MCF) in the calculation of LFG generation at unmanaged disposal sites to account for aerobic waste decay that does not produce methane.[13] The IPCC Model introduced this adjustment and assigns an MCF of 0.8 (20 percent reduction) for unmanaged sites greater than 5 meters deep and an MCF of 0.4 for unmanaged sites less than 5 meters deep.

The GMI models for China, Thailand, Philippines, Colombia, Mexico and Ukraine apply a "fire adjustment factor" to account for the consumption of organic material in fires that would otherwise have been available for LFG generation. Application of a fire adjustment factor requires obtaining information on the volume or surface area of waste areas affected and the severity of the fire (ranked as low, medium, or severe impacts).

6.5 Estimating Collection Efficiency

Site Conditions and Management Practices

Several of the GMI models automatically calculate collection efficiency based on user inputs in response to questions about site conditions and site management practices. To answer these questions, the model user should gather information on the following:

- **Site management practices**. Properly managed SWD sites will have characteristics (cover soils, waste compaction and leveling, control of waste placement, control of scavenging, control of fires, and leachate management systems) that allow achieving higher collection efficiencies than unmanaged dump sites.
- **Waste depth**. Shallow sites require shallow wells, which are less efficient because they are more prone to air infiltration. The GMI models apply discounts to collection efficiency when average waste depth is less than 10 meters.
- **Cover type and extent**. Collection efficiencies will be highest at sites with a low-permeable soil cover over all areas with waste, which limits the release of LFG into the atmosphere, air infiltration into the collection system, and rainfall infiltration into the waste. Information on the percentage of disposal area with daily, intermediate and final cover is needed for the GMI models to run collection efficiency calculations.
- **Base liner**. SWD sites with clay or synthetic liners will have lower rates of LFG migration into surrounding soils, resulting in higher collection efficiencies. Information on the percentage of the site lined with a synthetic or clay liner is needed for the GMI models to run collection efficiency calculations.
- **Waste compaction**. Uncompacted waste will have higher air infiltration and lower gas quality, and thus lower collection efficiency. The GMI models require information on whether waste is compacted on a regular basis.
- **Size of the active disposal ("working face") area**. Unmanaged SWD sites with large waste placement areas will tend to have lower collection efficiencies than managed sites where disposal occurs in smaller waste placement areas.
- **Leachate management**. High leachate levels can dramatically limit collection efficiencies, particularly at sites with high rainfall, poor drainage and limited soil cover. Evidence of high leachate levels includes leachate seeps, surface ponding and runoff channels. Severity of leachate impacts is calculated in the GMI models based on precipitation rates and whether the evidence of high leachate levels occurs only after rainstorms.

[13] Unmanaged disposal sites do not meet IPCC's definition of managed solid waste disposal sites, which "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." (IPCC, 2006. Table 3.1). Sites where management practices are unknown are assumed to be unmanaged.

The GMI models, which automatically estimate collection efficiency, use the above information to calculate discounts to the maximum collection efficiency that is achievable with a comprehensive and efficiently operated GCCS. Other GMI models provide instructions in the user's manual on how to apply the discounts to calculate collection efficiency. IPCC Model users can refer to one of the GMI user's manuals (such as the Central America Model) for instructions on collection efficiency calculations.

Collection System Coverage

While site conditions and management practices set limits to achievable collection efficiency, the primary determinant of collection efficiency is the fraction of total waste that is under active LFG collection, known as "collection system coverage." Collection system coverage is calculated by dividing the surface area of waste that is within the influence of the existing or planned extraction wells by the total surface area of the site. "Collection system coverage" accounts for the extent to which wells are installed in all areas with waste and the extent to which the installed wells are effectively drawing LFG from the waste. Collection system coverage will be zero before system start-up date and will vary over time at active disposal sites as new disposal cells are developed and collection systems are expanded. Unmanaged SWD sites, and sites that are still receiving wastes and that have high food waste disposal rates and or wet climates, will have considerably less than 100 percent collection system coverage as a result of the following issues:

- Sites with security issues or large numbers of uncontrolled waste pickers will not be able to install equipment in unsecured areas and cannot achieve good collection system coverage.
- Extraction wells cannot operate without significant air intrusion in areas with uncovered waste, so well installation will be delayed until a cover is installed. When combined with security issues, this limitation often means that no wells can be installed in an area until it is closed, capped with a final cover and protected with security fencing.
- Extraction wells cannot be installed in areas with steep, unstable slopes, soil stockpiles or other locations where equipment access is restricted.
- While the GMI models include discounts to collection efficiency to account for shallow waste depths and high leachate levels, additional discounts may be required to account for limited collection system coverage in areas where shallow waste or elevated leachate levels prevent well installation or restrict it to shallow depths.
- If there is a long time lag (more than 1 to 2 years) between waste placement and well installation in the waste as a result of the issues described above, there can be an especially large decline in the amount of LFG available for collection at sites with high food waste disposal and rainy climates. This combination of highly degradable waste and high moisture results in high LFG generation rates and rapid consumption (short half-life) of much of the organic material during the time period before there is collection.
- Many countries lack experience and expertise in designing, installing, operating and maintaining LFG collection systems. These countries can seek outside help, but LFG experts from other countries may not be familiar with the different conditions encountered in developing countries, where their methods may not be successful. Programs such as the GMI help to build the LFG project capacity of developing countries.

Achievable Collection Efficiencies. Given that conditions at some sites often limit the achievable collection efficiencies, the following are recommended maximum collection efficiency values that should not be exceeded when applied to LFG generation projections to estimate LFG collection:

- At active dump sites: 50 percent in wet climates and 60 percent in dry climates.
- At closed dump sites: 70 percent.
- At active engineered landfills: 75 percent in wet climates and 80 percent in dry climates.
- At closed engineered landfills: 85 percent.

Note that these are maximum values that can be achieved only under the best conditions and most successful LFG project implementation efforts, given the limitations of each SWD site category. Actual collection efficiencies achieved will be lower in most cases where site conditions and available resources to address problems that arise limit LFG collection.

6.6 LFG Model Uncertainty and Performance

LFG model uncertainty has been addressed in discussions of the following topics:

- The inability to validate LFG generation models, particularly when used for emissions estimates, based on the lack of measured values for most parameters in the LFG generation equation.
- The inability to directly measure conditions inside the waste mass that influence LFG generation such as moisture (thus requiring the use of a surrogate, precipitation data, in the model).
- The long list of data required to run models, and the need to evaluate data and use alternative methods for calculating missing data caused by data problems or unavailability.
- The many issues encountered at unmanaged disposal sites, which are very different from managed landfills and have impacts on LFG generation and recovery that are difficult to quantify.

Instructions for the IPCC Model provide a thorough discussion of factors contributing to model uncertainties and divide them into uncertainties created by the first-order decay calculation method, model input parameters and data. Ultimately, model uncertainty or accuracy can be tested only by comparing model estimates of LFG recovery against future measurements of flow data. Because of this requirement, the list of potential sources of error includes the ability to accurately predict future conditions, as well as model methods, parameters and historical data inputs.

IPCC concludes that uncertainties posed by the calculation method are much less than uncertainties that result from parameter selection or data and provides a table assigning an estimate of uncertainty to each parameter or data category. Most of the estimates indicate significant uncertainty (ranging from 5 percent to 50 percent) which, when combined, indicate a very large potential for error. Although multiple errors can often offset each other, which may limit the accumulation of error, the overall potential for error is significant. Modelers need to be vigilant in their efforts to limit potential error at every step in the process.

Best Practices for Landfill Gas Modeling

Estimating the volume of LFG generation from a landfill is a critical component of a project assessment and conceptualization because the collection projections are used to estimate the size of the project, expected revenues, project design requirements and capital and operating costs. However, accurately projecting the total LFG and methane generation for a landfill can be difficult for many stakeholders. It requires selection and use of an appropriate LFG model among several options, consideration of local conditions that affect LFG generation, and an understanding of the uncertainty inherent with LFG modeling. The value of LFG estimates also depends on the quality of data used in the model; proper consideration of factors such as annual waste composition, disposal rates and estimated growth rates; and the participation of an experienced LFG modeler.

CHAPTER 7

Project Economics and Financing

The economic viability for LFGE projects relies heavily on identifying suitable financing mechanisms, evaluating the economic feasibility of various options, and selecting the most viable option to meet the goals of stakeholders (for example, financial objectives, public health benefits, environmental protection and climate change mitigation). Chapter 5 presented an overview of the major types of market incentives that can support LFGE projects, and Chapter 6 presented best practices for using models to estimate LFG capacity. This chapter examines financial issues at the project level, discusses the critical factors and mechanisms in evaluating the economics of LFGE project development, and provides guidance on the process for performing an economic analysis.

The project economic assessment process typically includes four broad steps, as shown in Figure 7-1. These steps are often completed several times for each project option as initial decisions are made that affect the assessment and as additional information becomes available. The following sections discuss the assessment process in greater detail and provide examples and resources that aid in the evaluation.

STEP 1	• Identify Project Options • Assess Funding Mechanisms and Instruments	Repeat for each project option and to refine assessments
STEP 2	• Estimate Project Capital and O&M Expenses • Estimate Energy Sales and Carbon Revenue Streams	
STEP 3	• Conduct an Economic Assessment	
STEP 4	• Evaluate Economically Feasible Options	

Figure 7-1. LFGE Project Economic Assessment Process

7.1 Step 1: Assess Funding Mechanisms and Instruments

Identification of suitable financing and investment mechanisms that apply to funding LFGE projects are common concerns to every project developer. In some countries, these concerns can be compounded by additional challenges, such as a lack of local lenders or inexperience in financing LFGE projects. Consequently, one of the first and most important steps in the project evaluation process is to identify and assess the available funding mechanisms and instruments. The party developing the LFGE project (such as a landfill owner or third-party developer) should examine the sources and types of financing available because these factors need to be included and evaluated in the economic analysis. In some cases, sufficient financial support may be fully available with acceptable terms from a single resource; in other cases, the full amount will require the use of a combination of financing options.

A large number of financing instruments have been established over the years to support development of renewable technologies and projects. LFGE projects can be financed through a variety of mechanisms and organizations, such as carbon revenues through the CDM or the JI mechanisms of the Kyoto Protocol, various types of banks, equity and private investors, and internal resources. The project finance options and sponsoring organizations discussed in this section do not represent an exhaustive list, but serve to highlight commonly used and representative financing opportunities.

Financing through the Kyoto Protocol and Other GHG Emission Reductions Mechanisms

As introduced in Chapter 5, the Kyoto Protocol of the United Nations Framework Convention on Climate Change sets the framework for meeting the GHG emission reduction objectives from certain industrialized countries through the use of CERs under the CDM or Authorized Account Units (AAUs) under the JI mechanism.

The CDM and JI mechanisms can be important sources of financing for LFGE projects. Figure 7.2 shows the percentage of CDM projects that support LFGE projects. The potential buyers of emission reductions may be governments, private companies, corporations, foundations and multilateral agencies such as the World Bank. Many international LFG and LFGE projects are financed through the sale of CERs or AAUs to a third party. Other projects have been financed by The Word Bank using contracts to purchase the CERs once they have been verified by a third-party auditor and issued as Kyoto-compliant assets. A smaller number of projects are self-financed by project owners who sell the CERs to various carbon funds. However, carbon reductions under either of these mechanisms must be approved by the relevant institution, such as the CDM Executive Board of the UNFCCC, to be considered as future revenue until.

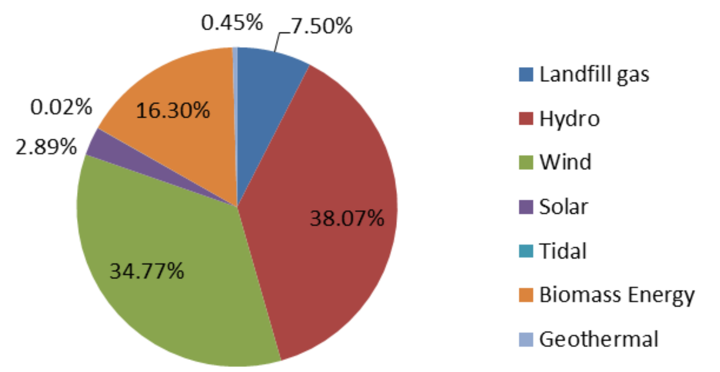

Figure 7-2. Percentage of LFGE CDM Projects

More recently, the UNFCCC established a Programme of Activities (PoA), a voluntary coordinated action by a private or public entity that implements a policy, measure or stated goal leading to anthropogenic GHG emission reductions. For example, activities coordinated under a PoA can be registered as a single CDM project activity, which could advance implementation of smaller projects and facilitate easier and less costly project development (for example, through aggregating several small LFGE projects to improve project economics).

While CDM and JI mechanisms have been the driver for numerous projects, uncertainty exists for project development in the post-Kyoto period (after 2012). As global policy and implementation details continue to evolve, it is important for the developers of new projects to understand any changes to the current scheme that may affect the requirements for emission reductions to qualify for compliance.[1]

During international climate talks in December 2010 in Cancun, Mexico, attendees agreed to mobilize $100 billion per year by 2020 (referred to as the Green Climate Fund) for meaningful climate change mitigation and adaptation measures[2]. Thus, alternative financing mechanisms may emerge to fill a potential void created by changes to the CDM and JI mechanisms. In addition, the EU Emissions Trading Scheme will continue to accept emission reductions under Phase III (2013 to 2020), but the reductions or offsets will be limited to Least Developed Countries. The World Bank funds (discussed below) — which are used to purchase GHG emission reductions from projects in the developing world or in countries with economies in transition — will likely continue to be available and may emerge as the predominant source of emission reduction financing In the post-Kyoto period.

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[1] These updates can be found at http://unfccc.int/2860.php.
[2] British Embassy Berlin. “The Road to $100 bn.” http://ukingermany.fco.gov.uk/en/news/?view=News&id=658618582.

Renewable energy programs and incentives (unrelated to carbon financing) may also be available in some countries and should be evaluated in considering project revenues and economic feasibility. Additional GHG reduction crediting mechanisms and programs also exist, such as mandatory markets like the EU Emissions Trading Scheme (EU ETS), The Netherlands CO_2 emission trading system, and the New Zealand ETS (the first mandatory, economy-wide scheme outside Europe), and voluntary markets such as the Verified Carbon Standard (VCS) and over-the-counter (OTC) trading of carbon derivatives. Alternative market instruments are being considered or are emerging in countries such as Australia, Brazil, China, India, Mexico and the Republic of Korea.[4] For a more detailed discussion of project revenues, including cash flows to projects from sales of electricity, steam, gas, or other derived products, see Section 7.2.

Example: Other Funding Mechanisms

The German Renewable Energy Sources Act prescribes fixed tariffs of 9 cents/kWh for systems up to and including 500 kW and 6.16 cents/kWh for plants between 500 kW and 5 MW that grid operators must pay for electricity generated from LFG. Over the last 5 years, more than 80 LFG electric projects have been built or are under development in Poland as a result of Poland's FIT and other drivers.[3]

Financing through Banks and Bilateral Export and Investment Promotion Agencies

Banks play an important role in providing credit to LFGE projects. Many banks offer special loan conditions for governments and companies in this sector, such as low interest rates, long amortization schedules and special financing packages. Most commercial banks require interest to be paid soon after the term of the loan is over, but some development banks may be willing to provide a longer repayment term. Credit terms and conditions are affected by the project developer's financial standing, project development experience and the status of existing agreements and permits. Providing adequate guarantees for project development can be one of the major barriers for developing LFGE projects.

Use of Carbon Credits

Carbon credits, such as CERs, can improve the economics of LFGE projects. Obtaining traditional debt financing through banks may be more likely for LFGE projects that incorporate carbon credits.

Agreeing on the projected volume of LFG to be obtained from the landfill project activity is often the biggest challenge faced both by project developers approaching financial institutions and by financial institutions appraising a project. If an energy project is being considered for a landfill where LFG is already being collected and flared, then the expected volume of LFG can be predicted with more certainty. Otherwise, it is important to avoid overestimating methane recovery by using appropriate LFG modeling techniques and making realistic assumptions about gas collection efficiency that consider site-specific conditions. As discussed in Chapter 6, LFG modeling tools have been developed for several countries as part of GMI.[5] Developers for electricity generation projects face additional challenges in obtaining financing, which includes accounting for uncertainty that the electricity produced from LFGE project will be connected to the local or regional grid at a favorable price.[6] Several types of banks that finance LFGE projects are described below.

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3 Piotr Klimek. "Landfill Gas to Energy Projects in Poland." Presented at the GMI Partnership-Wide Meeting, Krakow, Poland, 14 October 2011. http://www.globalmethane.org/documents/events_land_101411_tech_klimek.pdf.

4 The World Bank. "State and Trends of the Carbon Market 2010." May 2010. http://siteresources.worldbank.org/INTCARBONFINANCE/Resources/State_and_Trends_of_the_Carbon_Market_2010_low_res.pdf.

5 These countries include Central America, China, Colombia, Ecuador, Mexico, Philippines, Thailand and Ukraine. Additional information can be found at http://www.globalmethane.org/tools-resources/tools.aspx#three

6 U.S. EPA. *LFG Energy Project Development Handbook*. http://www.epa.gov/lmop/publications-tools/handbook.html

Multilateral Development Banks (MDB) are institutions that provide financial support and professional advice for economic and social development activities in developing countries.[7] MDBs include The World Bank Group and four Regional Development Banks: The African Development Bank (AfDB), The Asian Development Bank (ADB), The European Bank for Reconstruction and Development (EBRD) and The Inter-American Development Bank Group (IDB).

The role of the World Bank has been to catalyze a global carbon market that reduces the cost of achieving GHG reductions and supports sustainable growth for the developing world.[8] The World Bank works with emission reduction projects to further develop them to the stage of a carbon finance transaction and official recognition as a CDM project.

- The World Bank's Carbon Finance Unit (CFU) is composed of 13 funds, each with a different sectoral or geographic focus.[9] The CFU contracts to purchase emission reductions for one of these funds, the Prototype Carbon Fund (PCF). The PCF contracts to purchase emission reductions annually or periodically once they have been verified by a third-party auditor.
- The World Bank Climate Investment Funds (CIF) are a pair of funds to help developing countries pilot low-emission and climate-resilient development. With CIF support, 45 developing countries are piloting transformations in clean technology, sustainable management of forests, increased energy access through renewable energy and climate-resilient development.
- The Clean Technology Fund aims to promote low-carbon economies by helping to finance deployment of commercially available cleaner energy technologies in developing countries through investments in support of credible national mitigation plans that include low-carbon objectives.
- The Strategic Climate Fund will help more vulnerable countries develop climate-resilient economies and take actions to prevent deforestation.

Example: Multilateral Development Bank in China

IFC and the Industrial and Commercial Bank of China (ICBC) have developed a special China Utility-Based Energy Efficiency Program (CHUEE), which is designed to give loans to renewable energy and energy efficiency projects, including LFGE projects. CHUEE seeks to bring together financing institutions, utility companies and suppliers of energy efficiency equipment to "create a new financing model for the promotion of energy efficiency."

Sub-Regional Banks, established for development purposes, are also classified as multilateral banks as they are owned by a group of countries. Sub-regional banks include:

- Corporación Andina de Fomento (CAF)
- Caribbean Development Bank (CDB)
- Central American Bank for Economic Integration (CABEI)
- East African Development Bank (EADB)

[7] The World Bank. "Multilateral and Bilateral Development Agencies." http://web.worldbank.org/WBSITE/EXTERNAL/EXTABOUTUS/0,,contentMDK:20040612~menuPK:41694~pagePK:51123644~piPK:329829~theSitePK:29708,00.html.

[8] The World Bank. "10 Years of Experience in Carbon Finance." http://siteresources.worldbank.org/INTCARBONFINANCE/Resources/Carbon_Fund_12-1-09_web.pdf.

[9] Although these funds do not target LFGE projects specifically, the objectives of many of the funds (such as supporting the implementation of renewable energy projects) are compatible with LFGE projects.

Multilateral Financial Institutions (MFI) include banks and funds that lend to developing countries. They differ from the MDBs in that they have a more narrow ownership and membership structure or focus on special sectors or activities. MFIs include:

- The European Commission and The European Investment Bank (EIB)
- International Fund for Agricultural Development (IFAD)
- The Islamic Development Bank (IDB)
- The Nordic Development Fund (NDF) and The Nordic Investment Bank (NIB)
- The OPEC Fund for International Development (OFID)

National and Local Banks provide credit lines for environmental projects. Some national and local banks offer special credit lines for GHG emission reduction projects with lower interest rates and longer terms.

Example: National Bank

In Brazil, Banco do Nordeste's Cresce Nordeste program offers loans with low interest rates and long repayment terms to environmental projects, including alternative energy generation and waste treatment projects, among others. Cresce Nordeste operates as part of a program aimed at providing credit to entrepreneurs investing in Brazil's Northeast region.

Bilateral Banks and Export and Investment Promotion Agencies seek to promote and finance projects that are of strategic importance to developing countries. More than two dozen bilateral development institutions and dedicated initiatives exist throughout Europe, North America, Australia and Japan.[10] Examples of bilateral institutions include:

- The Export-Import Bank of the United States (Ex-Im Bank) has a Congressional mandate to support renewable energy and has been directed that 10 percent of its authorizations should be dedicated to renewable energy and environmentally beneficial transactions. Ex-Im Bank has dedicated credit officers to process environmental transactions and offers a number of incentives, including durations up to 18 years, 30 percent local costs support, capitalized interest during construction, an interest rate lock on direct loans, and the ability to pay the exposure fee as a margin over an interest rate.[11]
- The Overseas Private Investment Corporation (OPIC) supports U.S. investment in emerging markets worldwide by providing investors with financing, guarantees, political risk insurance and support for private equity investment funds.
- Germany Trade and Invest supports the promotion of renewable energy technologies, in association with the German Technical Cooperation, through the Project Development Programme (PDP) for developing countries.
- The Commonwealth Development Corporation (CDC), owned by the UK government, directly mobilizes private investment in developing countries. By investing in a commercially sustainable manner in the developing world, CDC strives to attract other investors by demonstrating success.

For a more comprehensive listing of bilateral export and investment promotion agencies, see the World Association of Investment Promotion Agencies' list of Outward Investment Agencies.

[10] http://www.climatefundsupdate.org/global-trends/global-finance-architecture.

[11] Export-Import Bank of the United States. "Key Industries at Export-Import Bank: Renewable Energy, Power Generation and Related Services." http://www.exim.gov/products/special/keyindustries.cfm#renew.

Financing through Private Investors and Leasing Arrangements

In this approach, investors fund all or a portion of the LFGE project. Potential investors include developers, equipment vendors, gas suppliers, industrial companies and investment banks. Private investors invest in companies with emission reduction project portfolios as well as in individual projects, depending on the nature of the opportunity. Some private investors develop and own the emission reduction projects, whereas others provide portfolio equity and sell their equity shares over time. Both groups of investors work with financial institutions to secure financing for the LFGE projects in their portfolios. Private investors generally need to obtain a higher return from their investments than banks.

Lease financing may be an option for some LFGE projects. In this approach, the project developer leases all or part of the project assets to an investor. There are two generally used forms of lease financing for LFGE projects.

Sell and Lease Back financing is used when a tax equity investor claims the tax benefits and passes part of the value in the rent it charges the developer for use of the project. The developers must pay the full value at the end of the lease if they want to keep the project.

Lease Pass-through financing is used when the developer leases the project to a taxable investor for a term of years (for example, 5 years) when tax benefits or grants are passed to the investor. When the lease terminates, the developer regains control of the project at no cost. [12]

Private equity investments are primarily made by private equity firms, venture capital firms, or angel investors. Each type of investor has its own set of goals, preferences and investment strategies and provides working capital for a project to support various outcomes (such as return on investment). Equity financing can provide benefits to the project owner by offsetting certain costs (for example, capital cost) and spreading the risk to other parties. The rate of return required by investors is generally high and the project owner usually must give up some control of the asset to the investors.

Example: Private Investment

Sistemas de Energía Internacional SA (SEISA) is a Mexican engineering company that specializes in energy use services. The company offers lease services, through which it designs, builds and manages project development. When the agreement is terminated, the customer may choose to purchase and operate the facility, or the customer may acquire the assets and leave SEISA's team of experts in charge of the facility O&M. In 2001, SEISA participated in design, construction and implementation of Latin America's first biogas energy use project. The recovered biogas is now used to operate seven internal combustion engines, each of which produces 1 MW of power.

Financing through Grant Opportunities

Grants from government sources or development banks may provide project funding. For example, the North American Development Bank (NADB) offers grants to public and private entities involved in developing environmental infrastructure projects in the border region between the United States and Mexico. The availability of grant funding varies significantly from country to country.

[12] J. Marciano. "Financing Strategies for Landfill Gas Projects." http://www.epa.gov/lmop/documents/pdfs/conf/13th/marciano_landfill_gas.pdf.

Financing through Internal Resources

Because of their ability to levy taxes, government entities have financing options that are not typically available to the private sector. These funding options are described in Chapter 5.

Municipal Bond Financing is used when the local government issues tax-preferred bonds to finance the LFGE project at municipally owned landfills or for a municipal end user.

Direct Municipal Funding uses the operating budget of the city, county, landfill authority or other municipal government to fund the LFGE project. It eliminates the need to obtain outside financing.

7.2 Step 2: Estimate Project Capital and O&M Expenses and Revenues, and Energy Sales and Carbon Revenues

This section discusses the costs and revenues for implementing an LFGE project at an existing landfill. Costs associated with the development and operation of the landfill itself are not addressed (including costs related to site acquisition, landfill permits, landfill operations, landfill closure and site remediation).

Quantify Capital and O&M Costs

LFGE project costs generally consist of capital costs, such as the purchase and installation of equipment, and O&M expenses of the project. Cost elements common to LFGE projects are listed below.

Interchangeable Terms

In the finance sector, capital costs may be referred to as capital expenses (CAPEX) while O&M costs may be referred to as operating expenses (OPEX).

Capital costs include:

- Initial cost of the equipment, equipment housing, drilling and installation (including import duties and any related taxes)
- Design, engineering and administration (internal or external engineering or design)
- Permits and fees
- Site preparation and installation of utilities (such as the electrical interconnection)
- Startup costs and working capital.

O&M costs include the annual costs associated with LFGE equipment (including the gas wells, treatment system and pipelines):

- Parts and materials
- Labor and training
- Utility costs
- Financing costs (such as legal, closing costs and origination fee)
- Taxes
- Administration
- Lease or rental fees.

Given the wide range of possible development issues across different projects and countries, the size of each of these types of costs can vary greatly; furthermore, this list cannot be considered exhaustive. For example, additional costs may be realized, such as registration and verification fees and other transaction costs for participation in CDM or JI.

Capital and Operational Cost Considerations

Capital and operating expenses vary depending on the technology selection (producing electricity for sale to the grid or transmitting the gas to a direct end user for use in a boiler) and should be factored into a financial model analysis. In addition, equipment suppliers should be contacted for price quotes on specific equipment (such as the piping, flare and engine) that should also be factored into the financial assessment. The following sections describe the specific factors that may influence the project costs for the two most common LFGE project types: electricity generation and direct use. Developers may want to evaluate the costs associated with each of these project types to ensure that the more advantageous option is correctly identified.

Electricity Generation. The most common technology options available for electricity generation projects are internal combustion engines and gas turbines. Each of these technologies is generally suited to certain project size ranges, as shown in Table 7-1. For example, standard internal combustion engines are well-suited for small- to mid-size projects, whereas gas turbines are best suited for larger projects. Internal combustion engines have a comparatively low capital cost per kW, but have higher O&M costs than gas turbines. Typical O&M costs cover training and salaries for electricity plant operators, replacement parts and other materials, and routine service. The costs presented in Table 7-1 are for typical U.S. installations; actual project costs will vary widely from these figures based on country-specific factors, such as are discussed below for direct-use projects. In addition, interconnection and annual transmission costs can vary significantly depending on project size, utility policies and requirements.

Table 7-1. Electricity Generation Project Technologies — Cost Summary

Technology	Optimal Project Size Range	Typical Capital Cost ($/kW)*	Typical Annual O&M Cost ($/kW)*
Small Internal Combustion Engine	≤ 1 MW	$2,300	$210
Large Internal Combustion Engine	≥ 800 kW	$1,700	$180
Gas Turbine	≥ 3 MW	$1,400	$130

* 2010 U.S. dollars.[13]

The modular nature of internal combustion engines and gas turbines provides flexibility for incremental capacity increases in response to greater production of LFG.[14] Internal combustion engines can be added in smaller incremental stages than gas turbines for a lower capital cost.

In combined heat and power (CHP) projects, the thermal energy cogenerated by LFGE projects can be used for on-site heating, cooling or process needs, or piped to nearby industrial or commercial users to provide a second revenue stream for the project.[15] CHP is often a better economic option for end users located near the landfill or for projects where the end user has sufficient demand for both the electricity and the waste heat.[16]

Direct Use. Direct-use projects, such as boilers, furnaces, dryers, kilns and infrared heaters, may be viable options if an end user is located within a reasonable distance from the landfill. The location of the

[13] U.S. EPA. *LFG Energy Project Development Handbook*. http://epa.gov/lmop/publications-tools/handbook.html.
[14] Ibid.
[15] U.S. EPA Combined Heat and Power Partnership. "Catalog of CHP Technologies." http://www.epa.gov/chp/documents/catalog_of_%20chp_tech_entire.pdf.
[16] U.S. EPA. 2012. *Landfill Gas Energy: A Guide to Developing and Implementing Greenhouse Gas Reduction Programs*. http://www.epa.gov/statelocalclimate/documents/pdf/landfill_methane_utilization.pdf.

end user will dictate the necessary length and location of the LFG pipeline. The costs of LFG pipelines will be affected by the required length and also may be affected by obstacles along the route, such as highways, railroads or water bodies. In addition, the size of the pipeline can affect project costs. For projects with increasing gas flow over time, it is often most cost-effective to size the pipe at or near the full gas flow expected during the life of the project and to add compression equipment as gas flow increases.

Costs for direct-use projects may vary depending on the requirements of the end user in terms of quantity and quality of LFG. LFG treatment will be necessary for end users requiring higher quality LFG, which may be cost-prohibitive for some projects. Even lower quality LFG may require supplementary moisture removal.[17] Direct-use project costs will typically involve the following major items:

- LFG compression and treatment (moisture and particle removal) to condition gas for the end user's equipment (see Chapter 5).
- A gas pipeline to transport LFG to the end user.

O&M considerations for direct-use projects generally include parts and materials as well as the labor necessary for condensate management systems (or any other LFG treatment systems used), operation and maintenance of the pipelines to transport LFG to end users, and maintenance of the end user equipment (if specified in the contract).

Existing boilers, furnaces, dryers and kilns require modifications to utilize LFG. The costs associated with the retrofit will vary depending on type of combustion unit, fuel use and age of the unit. In addition, the end user must invest in equipment that is capable of switching between LFG and traditional fuels to manage the long-term uncertainty and variability of LFG flow.

Infrared heaters and leachate evaporators do not require retrofits, but they carry their own cost considerations. In light of the seasonal nature of heating requirements, infrared heaters may not be cost-effective for some sites as a stand-alone project. However, infrared heaters work well, especially in colder climates, when paired with another project at the site since they can use a small amount of leftover LFG. Leachate evaporators can be cost-effective in situations where leachate disposal is expensive or non-existent (no treatment facility that can accept leachate).

Table 7-2 provides direct-use project cost figures for a typical U.S. project. Costs of LFGE projects, even those using the same or similar technologies, vary widely based on the specific nature of the landfill sites and country- and region-specific factors such as duties and taxes (for example, value added tax [VAT]), currency and business risks, availability of materials, labor costs and permitting. For example, projects in Argentina may achieve savings by using LFG flares that are manufactured domestically but may have to pay higher costs for LFG internal combustion engines that need to be imported.

Table 7-2. Direct-Use Project Components — Cost Summary

Component	Typical Capital Costs*	Typical Annual O&M Costs*
Gas compression and treatment	$565/m^3/hr	$53/ m^3/hr
Gas pipeline and condensate management system	$205,000/kilometer (km)	Negligible

* 2010 U.S. dollars, based on a 1,700 m^3/hr system.[18]

[17] ESMAP. "Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean." http://www.esmap.org/esmap/node/1106.

[18] U.S. EPA. *LFG Energy Project Development Handbook*. http://epa.gov/lmop/publications-tools/handbook.html.

Estimating Energy Sales and Carbon Revenues

Energy Sales Revenue

During the evaluation process, the anticipated revenue from energy sales and other sources or incentives can be estimated concurrently while project finance options are assessed. Energy sales and carbon revenues include cash flows to the project from sales of electricity, steam, gas or other derived products (carbon credits and renewable energy credits). The potential markets for these products are utilities, industrial plants, commercial or public facilities, and fuel companies.

Electricity Generation. The primary revenue from an electricity generation project is the sale of electricity to the local utility. This revenue stream is affected by the electricity buy-back rate, which is the rate at which the local utility purchases electricity generated by the LFGE project. Electricity buy-back rates for new projects depend on several factors specific to the local electric utility and the type of contract available to the project. Occasionally, the electricity is sold to a third party at a rate that is lower than the retail electricity rates. When the economics of an electricity project are assessed, it is also important to consider the use of electricity generated by the project for other operations at the landfill, which is, in effect, electricity that the landfill does not have to purchase from a utility. This electricity is not valued at the buy-back rate, but rather at the rate the landfill is charged to purchase electricity (the retail rate), which is often significantly higher than the buy-back rate.

Direct Use. The price of LFG dictates revenues for direct-use projects. Often, LFG prices are comparable to the price of natural gas, but prices will vary depending on site-specific negotiations, the type of contract and other factors.[19] In general, project developers should consider whether the price paid by the end user will provide energy cost savings that outweigh the costs of modifications to boilers, process heaters, kilns and furnaces that are necessary to burn LFG.

Carbon Revenue

The Kyoto Protocol has created a robust market for project development under CDM and JI. Many companies entered into this market to take advantage of development opportunities, with much of the early focus on landfill methane because of the perceived ease of development and relatively high value in the carbon market (because 1 ton of methane is equivalent to 21 tons of carbon dioxide). Some companies entered these markets with little experience in LFG project development, and the majority of projects (most are flare only) exist solely because of the price of carbon. Moreover, LFGE recovery is an emerging application in many developing countries, but existing waste management practices, site conditions, LFG collection system design and operation, and other factors that limit LFG recovery rates can create significant challenges to energy recovery. As a result, there is growing interest in building LFG development and operational capacity as well as advocating for energy generation in addition to flaring.

Most CDM landfill projects receive credits only for flaring the gas, and not for energy recovery applications, which may be a result of initial

> **Example: Energy Recovery Credit**
>
> Thailand has a feed-in premium for renewable power. In 2007, the Thai government began offering feed-in premiums on top of the regular tariff of $0.057-0.071 (USD) per kWh. Power generated from LFG is eligible for a $0.071 (USD) per kWh premium.[20]

[19] Ibid.

[20] International Energy Agency. Global Renewable Energy Policies and Measures. 2010. http://www.iea.org/textbase/pm/?mode=re&id=4410&action=detail.

uncertainty (before the gas collection system is installed) about the amount of gas that will be collected and the amount of electricity that could be produced, or can arise from concerns about whether utilities will purchase landfill electricity and for what price.

7.3 Step 3: Conduct an Economic Assessment

Economic Assessment Process

An economic feasibility assessment will help determine whether a project is right for a particular landfill. The general steps of this process are presented in Figure 7-3.

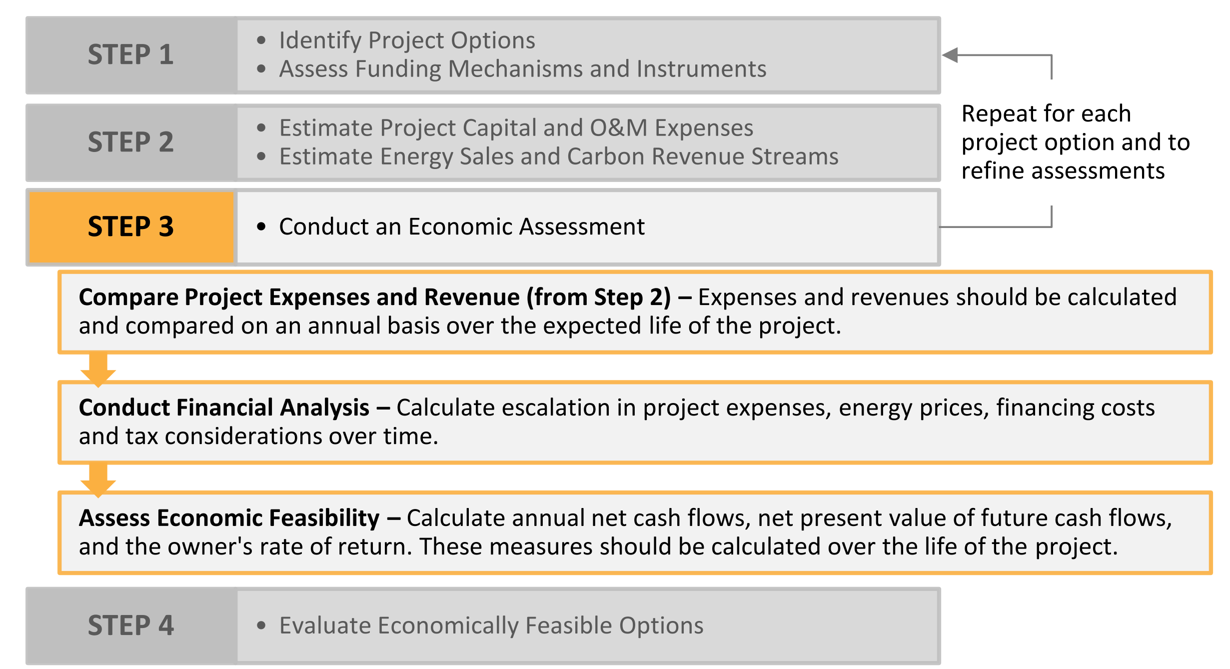

Figure 7-3. LFGE Project Economic Assessment Process

The expense and revenue information from Step 2 become inputs for the financial analysis of each of the project options. Few publically available financial models are available for this type of analysis, and those that are available may not be readily adapted to the country-specific circumstances of LFGE projects. Publically available models or spreadsheet-based analysis may be suitable for initial screenings; however, a more sophisticated financial analysis that carefully evaluates the many considerations outlined in this guide is required to determine an investment-ready project, whether to commit internal funds or to attract financial support from external entities. Project developers and investors usually perform financial analysis using a proprietary model that is customized to a region, country, or project level, which leads to a more robust financial "investment grade" analysis.

Assessment Guidelines and Tools

UNFCCC's Guidelines on the Assessment of Investment Analysis provides general guidance on calculations, format and comparing investment analyses for CDM projects.

UNFCCC's Tool for the Demonstration and Assessment of Additionality provides information on how to perform an investment analysis to determine if a proposed project is economically feasible.

7.4 Step 4: Evaluate Economically Feasible Options

After the initial economic analysis for each project option has been completed, a comparison should be made to decide which one best meets the objectives of project stakeholders. After the comparison, some options may emerge as clearly uncompetitive and not worth further consideration; alternatively, there may be one option that is clearly the superior choice and warrants a more detailed investigation. It is likely, however, that multiple energy project options appear to be viable, and it may be necessary to compare the economic analyses of each to select the most promising option, bearing in mind any non-price factors. Comparison methods to identify the most suitable option include:

1. Direct comparison among the options of the following financial metrics:
    a. Annual cash flows
    b. Net present value
    c. Debt coverage
    d. Rate of return
2. Consideration of non-price factors.

Non-price factors may impact the LFGE project and should be considered in the economic analysis. These non-price factors, which may not be quantifiable by the economic analysis (such as carbon credit and gas or electricity sales), include:

- ***Landfill gas availability, quality and quantity.*** There are three areas where LFG availability risks are found:
    1. The quantity of waste that may be available to produce the LFG;
    2. The characteristics of the waste that produce the LFG; and
    3. The in situ environment that controls the process of anaerobic decomposition that produces the LFG.

  Some of the risk or uncertainty can be alleviated by pump test data used in conjunction with the LFG modeling to demonstrate current LFG quality and quantities. The actual LFG flow will be a major factor in the amount of LFG available for direct use or in electricity generated, so accurate LFG models are necessary to evaluate the project's economics.[21] LFG availability risks can be managed by applying a conservative multiplier against the modeled LFG recovery curve to protect against any shortfall in available LFG. Staging the development in phases helps to minimize capital risks associated with over-sizing the LFG system, which is the major cost component of a project. Failure to address these risks can lead to projections of LFG (and corresponding revenues) that will not actually be realized, which can lead to higher project costs if the elements of the LFGE are oversized; it can also lead to financial performance that is below expectations. Using experienced modelers and project developers can reduce these risks (see Chapter 6).
- ***Equipment Performance and Reliability***. The technologies to collect and utilize the LFG fuel are generally well developed and are reliable, but site-specific conditions may limit the application and effectiveness of the selected technologies. However, well-trained operational staff who understand the nature of LFG recovery and the basic operations of the landfill can mitigate the risk.[22]

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[21] ESMAP. "Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean." http://www.esmap.org/esmap/node/1106.
[22] Ibid.

- ***Construction.*** The availability of materials (such as plastic piping) will affect construction schedules and, subsequently, costs of the project. In some countries, materials such as HDPE may not be available and will need to be imported or other locally produced materials (for example, stainless steel) may be substituted, which could increase the cost or affect the reliability of the project.
- ***Political and business risk factors.*** The following factors will affect project feasibility and should be considered: payment currency and method, business law, contract protections, and the possibility of corruption and of nationalization.[23] Many of these factors are not quantifiable but represent real barriers to a project. In addition, the currency used to pay the project investors may be a risk factor. However, it can be reduced by addressing the unit of currency (for example, local, Euro, or USD) in the contract to protect against currency devaluation.

There are additional factors that should be considered for electricity generation projects, such as:

- ***Access to electricity purchasers.*** The capacity and location of the point of interconnection to the local grid will affect overall feasibility of the project. The distance involved and the construction of a transmission line from the project to the interconnect point will affect the economics of the project (the cost of the transmission line will increase with increasing distance). Interconnection policies and charges can also increase costs.

Additional factors that should be considered for LFGE direct-use projects include:

- ***The end user's proximity to the landfill.*** The exact location of the LFG supply relative to location of equipment that will consume the gas, as well as the types of property that lie between, will affect project feasibility. For example, if any water bodies need to be traversed to route a pipeline, then the number of crossings, the distance of each water crossing (an example is directional boring under a stream or river will increase costs), and the availability of bridges should all be considered.
- ***The end user's LFG requirements.*** The quantity of LFG required by the end-user's boilers, furnaces, or kilns should be examined, as well as whether the end user's demand is relatively consistent (24-hours per day, 7 days a week) or varies on a daily or seasonal basis. One source of information is the quantity, heat input and pattern of use of the current fuels that would be displaced by LFG. Treatment requirements for the intended use should also be considered as discussed in Chapter 4.

Example: Political Risk Factor

For example, a developer enters into a 15-year contract with a landfill owner to build, own and operate an LFGE project only to have the project nationalized by the government in year six of the contract. How or will the developer be compensated?

Best Practices for Project Economics and Financing

The economic viability of a LFGE project relies heavily on identifying financial mechanisms to promote the development of LFGE resources. Options vary by country, but may include tax incentives, public-private partnerships, bond financing, direct municipal funding, loan guarantees and grants. It is important that stakeholders understand the range of financial mechanisms available for their LFGE project; evaluate carefully the economic feasibility of options, including non-price factors; and select the most viable project option to meet stakeholder goals.

[23] Ibid.

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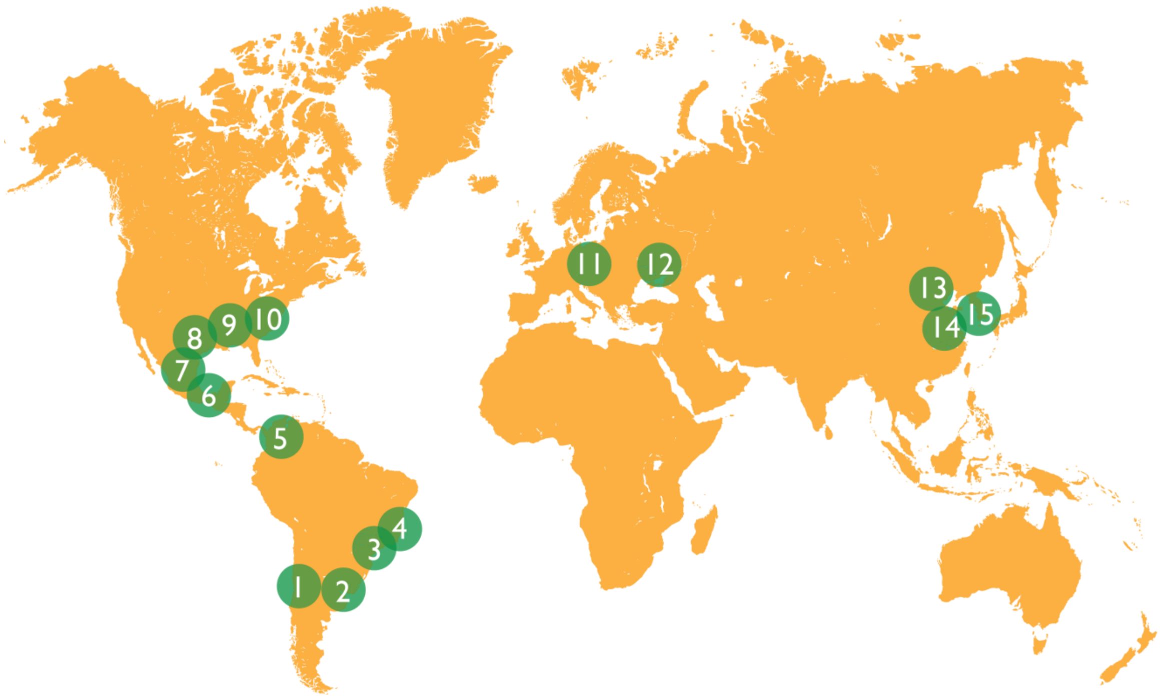
International Best Practices Guide for Landfill Gas Energy Projects

Appendix A
Case Studies

Appendix A features a selection of 15 case studies of successful LFG and LFGE projects in GMI Partner Countries. Each case study includes a brief summary of the project, identifies environmental and social benefits achieved and describes barriers that were overcome during the project. Resources for further information as well as contact information are also provided for each case study.

Case Studies



No.	Landfill Name and Location	Type of Project
1	Loma Los Colorados Landfill, Santiago, Chile	Electricity Generation
2	Norte III-B Landfill, Buenos Aires, Argentina	Flare Generation
3	São João Landfill, São Paulo, Brazil	Electricity Generation
4	Brazil MARCA Landfill, Cariacica, Brazil	Electricity Generation
5	Curva de Rodas and La Pradera Landfills, Medellín, Colombia	Flare
6	Nejapa Landfill, Nejapa, El Salvador	Electricity Generation
7	El Verde Landfill, León, Guanajuato, Mexico	Flare with Transition to Electricity Generation
8	Greenwood Farms Landfill, Texas, USA	Pipeline-Quality Gas
9	Star Ridge Landfill, Alabama, USA	Direct Use
10	Yancey-Mitchell County Landfill, North Carolina, USA	Direct Use
11	Barycz Landfill, Krakow, Poland	Electricity Generation
12	Closed Mariupol Landfill, Mariupol, Ukraine	Flare with Transition to Electricity Generation
13	Gaoantun Landfill, Beijing, China	Electricity Generation and Direct Use
14	Jiaozishan Landfill, Nanjing City, China	Direct Use
15	Daegu-Bangcheon-Ri Landfill, Daegu, Republic of Korea	Direct Use

More case studies are available on GMI's website at: http://www.globalmethane.org/projects/.

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CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: ELECTRICITY GENERATION

LOMA LOS COLORADOS LANDFILL ♦ SANTIAGO ♦ CHILE

The Loma Los Colorados Landfill is located 63 kilometers north of Santiago, Chile, near the village of Montenegro. The site operations are managed by **KDM Energia S.A.** The landfill receives 64 percent of the municipal solid waste (MSW) generated in the Santiago Metropolitan Area, providing waste disposal services to 24 municipalities. Since May 2003, more than 90 percent of the MSW deposited at the landfill has been transported by train from a transfer station located in Quilicura (in central Santiago). The landfill gas (LFG) energy project at Loma Los Colorados was registered as a **Clean Development Mechanism (CDM)** project on 17 March 2007. In 2009, Phase I of the LFG energy project started with an electricity generation capacity of 2 megawatts (MW). Currently Phase II is in operation, adding 9.9 MW for a total of 11.89 MW of installed capacity. Phase III will consist of the installation of an additional 21.78 MW capacity.

The electrical power system in Chile is one of the most permissive in the world. Laws No. 20018 and No.19440 allow the owner of any power generation facility to sell power to the interconnected grid and receive energy and capacity payments. Additional regulations were adopted in 2006, making grid access for renewable projects up to 20 MW more streamlined, improving economic and legal conditions for these projects.

Information on this project can be found on the UNFCCC website at: http://cdm.unfccc.int/Projects/DB/DNV-CUK1166695034.41/view, Project No. 0822: "*Loma Los Colorados Landfill Gas Project*."

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1996
Closure Year (expected)	2045
Total Waste in Place in 2010 (Mg)	22 million
Total Landfill Capacity (Mg)	100 million
Current Waste Footprint (ha)	70
Total Waste Footprint (ha)	210
Landfill Gas Energy Project	
Project Type	Electricity Generation
System Start Up	2009
Extraction Wells	280 vertical wells
Blower/Flare Station Capacity (m^3/hr)	10,000
Average Gas Flow in 2010 (m^3/hr)	8,000 at 48% CH_4
Average Emission Reduction (tonnes CO_2e/year)	582,400
Phase I - Total Investment (estimated, USD)	$3 million
Phase I,II and III - Total Investment (estimated, USD)	$40 million


Loma Los Colorados Landfill


MSW Transported by Rail


Blower/Flare Station


Loma Los Colorados Power Station

Environmental Benefits

- Project reduces approximately 582,400 tonnes of carbon dioxide equivalent (CO_2e) emissions annually.
- Mitigates slope stability and fire issues, as well as odors and LFG migration in surrounding neighborhoods.
- Minimizes air pollution, eliminating emissions of non-methane organic compounds, among other pollutants.
- Currently provides renewable energy for 200,000 people.
- Transportation of waste by rail offsets the emissions of previously used trucks.
- Provides economical renewable energy to the grid.
- Diversifies energy generation in the country, improving energy security.

Social Benefits

- Generates job opportunities associated with construction, operation, and maintenance of the project.
- Expected to provide improvements to public services in 14 rural communities in the area surrounding the landfill.
- Regularly visited by college and university students as a national demonstration project.

Past Barriers

- First CDM LFG energy project in Chile.
- The rural location of Loma Los Colorados Landfill and lack of nearby industry limited the potential for direct-use projects.
- Access of small renewable energy projects to the grid was limited by technical and legal issues.
- Energy pricing advantages for renewable energy were limited; in the open energy market, renewable sources must compete with larger-scale conventional sources.
- Strict oxides of nitrogen (NO_X) emission limits apply to the project, resulting in the need for costly NO_X abatement filters to be installed on each electricity generation unit's exhaust, as well as installation of expensive LFG siloxane removal systems.

Additional Information

- Renewable Energy Law 20257 was enacted in 2008, which established that at least 5 percent of all electricity must be from renewable sources in 2010, increasing to 10 percent by 2024. This renewable energy standard, combined with higher energy prices in the grid, has led to higher prices paid to renewable energy projects and has created a surge in renewable energy projects. There are no other requirements to obtain the right to connect to the electricity grid.
- The Phase II total investment includes future cost to reach their maximum projected capacity of 33.67 MW, LFG treatment and air emissions control systems, a 20-kilometer interconnection line, and a substation.

Contact Information

KDM Energia S. A.
Sergio Durandeau Stegmann, Gerente General
Av. Isadora Goyenechea No. 3621, Torre B Piso 14,
Las Condes, Santiago, Chile
Phone: +56 2 389-3228
sdurandeau@guk.cl

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CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: FLARE GENERATION

NORTE III-B LANDFILL ♦ BUENOS AIRES ♦ ARGENTINA

The **Norte III-B Landfill** is located in the District of San Miguel, a province of Buenos Aires. The landfill receives waste from the City of Buenos Aires and some municipalities located in the suburbs of Buenos Aires. Under a contract executed with **Coordinación Ecológica Area Metropolitana Sociedad del Estado (CEAMSE)** on 16 December 2005, **Ecoayres Argentina S.A.** was awarded a license to benefit from the biogas generated within the landfill. The main objective of this project is to reduce greenhouse gas emissions through extracting, collecting and burning the landfill gas (LFG) generated by the anaerobic decomposition of the waste, including use of some of the gas for electricity generation. Ecoayres Argentina S.A. was responsible for building and managing a gas capture, incineration, and electricity generation system and for making all necessary investments under **the Clean Development Mechanism (CDM)**, while CEAMSE will continue to own and manage the landfill.

Construction of the LFG capture and treatment system began in March 2006. In October 2006, Ecoayres Argentina S.A. completed the first step for project registration under the CDM by obtaining national approval from the host country, Argentina. Approval from the investment country, the United Kingdom, was obtained in November 2007. In February 2007, the project's validation process was completed by **Det Norske Veritas (DNV)**. Project registration by the **United Nations Framework Convention on Climate Change (UNFCCC)** was granted on 27 April 2007. The biogas engine began operation in August 2010.

Information on this project can be found on the UNFCCC website at: http://cdm.unfccc.int/Projects/DB/DNV-CUK1171431768.63/view, Project No. 0928: "*Methane Recovery & Effective Use of Power Generation Project Norte III-B Landfill.*"

PROJECT SUMMARY

General Landfill Facts		
Opening Year		2005
Closure Year		2010
Total Waste in Place (Mg)		15 million
Total Waste Footprint (ha)		82.5
Landfill Gas Energy Project		
Project Type		Flare with minimal electricity generation for self-supply
System Start Up:	Collection System Biogas Engine	March 2008 August 2010
Extraction Wells		270 vertical wells (operating and non-operating)
Blower/Flare Station Capacity (m^3/hr)		13,000
Average Gas Flow in 2010 (m^3/hr)		9,200 at 58% CH_4
Emission Reduction in 2010 (tonnes CO_2e)		669,600
Project Capital Cost (estimated, USD)		$10 million

Aerial View of the Norte III-B Landfill

LFG Collection Network

Environmental Benefits

- Reduced 669,600 tonnes of carbon dioxide equivalent (CO_2e) emissions in 2010.
- Mitigates odors.
- Minimizes explosion and fire hazards.
- Offsets the consumption of electricity from the public network and reduces greenhouse gas emissions.
- Minimizes air pollution, eliminating emissions of non-methane organic compounds, among other pollutants.

Social Benefits

- Generates new job opportunities and skill training associated with the project.
- Provides resources for research and technology transfer in Argentina.

Past Barriers

- Limited financing opportunities existed in Argentina for the project. The project would not be financially feasible unless it was registered as a CDM project and the project income captured from the sale of Certified Emission Reductions (CERs).
- Lack of locally available technology and experience for the construction, operation, and maintenance of the LFG energy system.

Additional Information

- The CDM registration cost for the project was $121,652 (USD).

Contact Information

Ecoayres Argentina S.A.
Ricardo Luis Bocco
Climate Change Unit, Manager
Buenos Aires, C1001AAS, Argentina
Phone: + 54 11 60912819
rbocco@bra.com.ar

Ecoayres Argentina S.A.
Juan Pablo Weihs
Engineering Department
Buenos Aires, C1001AAS, Argentina
Phone: + 54 11 60912822
jpweihs@bra.com.ar

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CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: ELECTRICITY GENERATION

SÃO JOÃO LANDFILL ♦ SÃO PAULO ♦ BRAZIL

The **São João Landfill** is located near the **Municipality of São Paulo**, Brazil's largest city and a producer of 15,000 tons of waste each day. The landfill has generated large quantities of landfill gas (LFG) since its inception, but most of the gas was lost to the atmosphere through passive venting. In June 1996, the U.S. Environmental Protection Agency (EPA) conducted a feasibility study which indicated that the São João Landfill could support an LFG electricity project.

In April 2006, the Municipality of São Paulo applied to register the project under the **United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM)** to procure project funding. São Paulo selected **Biogás Energia Ambiental S/A (Biogás)**, a Brazilian company specializing in LFG recovery, to manage the LFG capture project. Biogás commenced construction in May 2007 and began building the LFG electricity plant in June 2007. The project became operational in 2008. The plant combusts the LFG in 16 engines, each with a 1.54-megawatt (MW) capacity, and has a total electricity production capacity of 22.4 MW. Three flares destroy any LFG not used to generate electricity.

Information on this project can be found on the UNFCCC website at: http://cdm.unfccc.int/Projects/DB/DNV-CUK1145141778.29/view, Project No. 0373: *"São João Landfill Gas to Energy Project."*

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1992
Closure Year	2008
Total Waste in Place (Mg)	24 million
Total Waste Footprint (ha)	70
Landfill Gas Energy Project	
Project Type	Electricity Generation
System Start Up	2008
Extraction Wells	160 vertical wells
Blower/Flare Station Capacity (m^3/hr)	373 at 50% CH_4
Average Gas Flow in 2009 (m^3/hr)	11,555 at 50% CH_4
Emission Reduction in 2009 (tonnes CO_2e)	876,797
Project Capital Cost (estimated, USD)	$2.8 million

Photo of Degassing Station (1) & Power House (2)

Schematic of Degassing Station & Power House

Transmission Pipeline

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Environmental Benefits

- Reduced more than 3 million tonnes of carbon dioxide equivalent (CO_2e) emissions from 2007 to 2010.
- Prevents the release of greenhouse gas emissions and volatile organic compounds into the atmosphere, both of which contribute to air pollution and odors.
- Mitigates health risks, fire and leachate issues.

Social Benefits

- Projected to provide 85 percent of the total generated power to be dispatched into the S-SE-CO Brazilian Electric Grid, which has a total capacity of approximately 22.4 MW.
- Generates work opportunities related to construction, operation and maintenance of the project.
- Provides opportunities for student education through the "Ver de Perto" (Take a Closer Look) program and technology transfer.
- Promotes a model for LFG energy projects in Brazil that can be replicated.
- Provides emission reduction revenues to be shared with the Municipality of São Paulo, increasing available cash flow for other waste management investments such as closure of illegal dump sites, improved awareness of proper waste management practices and other environmental benefits.

Past Barriers

- The remote location, layout limitations and air emissions regulations governing NO_X were all barriers for the landfill.
- Miscalculations of the characteristics of the transmission line resulted in a misallocation of power capacity.
- The predominance of hydroelectricity production in Brazil limits incentives for investment in other renewable resources.
- LFG energy project opportunities are not fully explored in Brazil as a result of the lack of local technology and expertise.
- Lack of environmental regulations for active collection and flaring of LFG inhibits the cost-effectiveness of an LFG-fired electricity generation project.
- The São João project is the first of its size to be carried out in Brazil, where investor tolerance for risk has, in the past, limited the scale of financial resources needed for an LFG energy project of this magnitude. Carbon revenues were essential to moving the project forward.

Additional Information

- Even though it has not achieved its full energy production capacity, as of September 2009 the São João LFG energy project is the largest LFG energy project registered by the UNFCCC and is also among the largest LFG energy projects in the world.
- The project's CDM registration cost was $161,888 (USD).

Contact Information

Project Management:
ARCADIS Tetraplan
Cíntia Philippi Salles / Juliana Justi Pedott
São Paulo, SP, Brazil
CEP 01406 - 200
+55 11 3060-8457
cintia.salles@tetraplan.com.br
juliana.justi@tetraplan.com.br

Project Developer:
Biogás Energia Ambiental S/A
Júlio César do Prado
Av. Sapopemba, km 33, Bairro Jardin
São Paulo, SP, Brazil
CEP 08380 - 130
+55 11 2734-8862
julio@saojoao-ambiental.com.br

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CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: ELECTRICITY GENERATION

BRAZIL MARCA LANDFILL ♦ CARIACICA ♦ BRAZIL

The Brazil MARCA Landfill Gas Energy Project is a joint initiative between **EcoSecurities Ltd.**, an environmental finance company, and **MARCA Construtora e Servicos**, a local Brazilian landfill management company. The objective of the project is to collect and use the landfill gas (LFG) of the landfill managed by MARCA. **Biogas Technology Ltd (Biogas)** imported technology from the United Kingdom for the project. In February 2004, EcoSecurities Ltd. submitted its first Project Design Document (PDD) under the **Clean Development Mechanism (CDM)**. In July 2005, EcoSecurities Ltd. submitted PDD version 2, in which the baseline and monitoring methodology using AM0003, "Simplified financial analysis for landfill gas capture projects," was approved by the **United Nations Framework Convention on Climate Change (UNFCCC)**. The MARCA Landfill Gas Energy Project has an installed capacity of 11 megawatts. The developer is planning to expand the gas collection system to two recently closed cells to increase the gas flow to more than 2,500 cubic meters per hour (m^3/hr) and start generating electricity.

In August 2005, MARCA completed the first step for project registration under CDM by obtaining national approval from the host country, Brazil. Approvals from the investment countries of the United Kingdom and Japan were obtained in September and August 2005. In November 2005, the project's validation process was completed by **Det Norske Veritas (DNV)**. Project registration by the UNFCCC was granted on 23 January 2006.

Information on this project can be found on the UNFCCC website at: http://cdm.unfccc.int/Projects/DB/DNV-CUK1132565688.17/view, Project No. 0137: *"Brazil MARCA Landfill Gas to Energy Project."*

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1995
Closure Year (expected)	2017
Total Waste in Place in 2005 (Mg)	1.34 million
Total Landfill Capacity (Mg)	4.7 million
Landfill Gas Energy Project	
Project Type	Electricity Generation
System Start Up	July 2005
Extraction Wells	67 vertical wells
Blower/Flare Station Capacity (m^3/hr)	1,500
Average Gas Flow in 2011 (m^3/hr)	662 at 48% CH_4
Average Emission Reduction (tonnes CO_2e/year)	20,500
Project Capital Cost (estimated, USD)	$1.1 million

LFG Pipeline

Flare Station

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Environmental Benefits

- Reduces an average of 20,500 tonnes of carbon dioxide equivalent (CO_2e) emissions annually.
- Mitigates health risks, fire and leachate issues, and LFG migration in surrounding neighborhoods and reduces stratospheric ozone layer depletion and ground-level ozone creation.
- Minimizes air pollution, eliminating emissions of non-methane organic compounds, among other pollutants.

Social Benefits

- Provides electricity to the regional grid, thus displacing use of fossil fuels used for electricity generation.
- Promotes best practices to improve landfill management standards and contributes toward global sustainable development.
- Reduces risk of toxic effects from uncontrolled releases on local communities and the environment.
- Promotes clean technology and encourages less dependency on grid-supplied electricity throughout Brazil, which could be replicated across the region.

Past Barriers

- The conservative assumptions of the financial analysis conducted for the project show that, as an investment, the internal rate of return of the MARCA project is not an economically attractive course of action.
- The centralized preference of hydroelectricity to produce national electricity in Brazil dominates the energy sector and limits incentives for investment in renewable resources.
- The lack of adequate collection and treatment of LFG at the landfill site was imposed by regulatory requirements.

Additional Information

- The project has correctly applied the approved baseline and monitoring methodology (AM0003) which indicates that the project is not a likely baseline scenario and that emission reductions attributed to the project are additional to any that would occur in the absence of the project activity. The CDM registration cost for the project was $30,000 (USD).

Contact Information

Project Management:
EcoSecurities Ltd.
Pedro Moura Costa
Director
Oxford, UK
Phone: +44 1865 297483
Pedro@ecosecurities.com

Project Management:
MARCA Construtora e Serviços
Sérgio Almenara Ribeiro
Director
Cariacica, Espírito Santo, Brazil
Phone: +55 27 3337 7748
marcacs@escelsa.com.br

Project Developer:
Biogas Technology Ltd.
Ian Gadsby
Managing Director
Sawtry, Cambridgeshire, UK
Phone: +44 1487 831701
ian.gadsby@biogas.co.uk

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CASE STUDY

LANDFILL GAS PROJECT
PROJECT TYPE: FLARE

CURVA DE RODAS AND LA PRADERA LANDFILLS ♦ MEDELLÍN ♦ COLOMBIA

In January 2007, **Empresas Varias de Medellin (EEVVM),** a public utility company that owns both the **Curva de Rodas Landfill** and the **La Pradera Landfill**, signed an agreement with the **University of Antioquia** in Medellin to manage landfill gas (LFG) capture and flaring at the landfills. The agreement, unique in the LFG sector, was established not just to facilitate implementation of a project, but also to provide research and hands-on learning opportunities for the university and its engineering students. In addition, the university shares in the project revenue. The university issued a public request for proposals to find a strategic partner for development of the two sites as a single LFG flaring project under the **Clean Development Mechanism (CDM)**, resulting in the submittal of four proposals. In September 2007, the university awarded the project to **Consortium Green Gas Colombia (Green Gas),** and Green Gas started construction at the landfills in January 2008. Three months later, the university completed the first step for project registration under the CDM by obtaining national approval from the host country, Colombia. Approval from the investment country, the United Kingdom, was obtained after, and in August 2008, the project's validation process was completed using **TÜV** of Germany. The project was registered by the **United Nations Framework Convention on Climate Change (UNFCCC)** on 6 February 2009. Before this project, neither of the landfills had active treatment of LFG. Passive collection systems consisting of extraction wells existed, but many of the wells were not operational, and the existing flaring systems were highly inefficient in destroying methane. The project resulted in installation of active gas collection and flaring systems at both sites, with the possibility of an electricity generation component that could be added later at the La Pradera Landfill.

Information on this project can be found on the UNFCCC website at: http://cdm.unfccc.int/Projects/DB/TUEV-RHEIN1218645656.52/view, Project No. 2183: "*Curva de Rodas and La Pradera Landfill Gas Management Project*."

PROJECT SUMMARY

General Landfill Facts	Curva de Rodas	La Pradera
Opening Year	1984	2003
Closure Year	2003	2027 (expected)
Waste in Place in 2003 (Mg)	8.5 million	3.5 million
Total Landfill Capacity (Mg)	8.5 million	10.7 million
Current Waste Footprint (ha)	33	10
Total Waste Footprint (ha)	33	30
Landfill Gas Project		
Project Type	Flare	Flare
System Start Up	July 2008	December 2008
Extraction Wells	84 vertical wells	45 vertical wells
Monitoring Manifolds	10	5
Blower/Flare Station Capacity (m^3/hr)	3,000	2,000
Average Gas Flow in 2009 (m^3/hr)	634 at 37% CH_4	1,465 at 50% CH_4
Emission Reduction (tonnes CO_2e)	24,349 (2009)	179,574 (2010)


Curva de Rodas Landfill and Blower/Flare Station


La Pradera Landfill and Blower/Flare Station

Environmental Benefits

- Project reduced 203,923 tonnes of carbon dioxide equivalent (CO_2e) emissions in 2010.
- Mitigates odors, fire risks and LFG migration in surrounding neighborhoods.
- Improves slope stability as a result of the decrease of internal pressure in the landfill body through LFG extraction.
- Minimizes air pollution, eliminating emissions of non-methane organic compounds, among other pollutants.

Social Benefits

- Provides research and technology transfer opportunities for the University of Antioquia, as well as strengthens the position of the university as a top institution of higher learning in Colombia. Provides hands-on learning opportunities related to renewable energy and climate change for engineering students.
- Generates job opportunities associated with construction, operation, and maintenance of the project.
- A share of the Certified Emission Reduction (CER) proceeds is contributed to research at the University of Antioquia.
- An additional revenue share of the CERs is allocated to EEVVM to improve environmental management at the landfills, including landfill post-closure.

Past Barriers

- LFG modeling resulted in an overestimation of the LFG production from Curva de Rodas Landfill and subsequent misallocation of flare equipment.
- The rural location of La Pradera Landfill and lack of nearby industry limited the potential for direct-use projects.
- The low price of electric power and lack of renewable energy incentives limited the cost-effectiveness of an LFG-fired electricity generation project. In addition, the lack of significant on-site power demand limited the potential for a net metering or generation project.

Additional Information

- Lower than expected LFG flows from the Curva de Rodas Landfill resulted in insufficient LFG to efficiently operate the flare. As a result, the Curva de Rodas LFG project was decommissioned and the flare was moved to La Pradera Landfill in December 2009 to augment the existing flare capacity. Green Gas obtained UNFCCC approval under CDM for this modification to the Project Design Document (PDD) in February 2011.
- The CDM registration cost for the project was $31,964 (USD).

Contact Information

Project Management:
Universidad de Antioquia
Luis Fernando Restrepo Aramburo
Director Oficina de Asesoria Juridica
Medellín, Antioquia, Colombia
Phone: +57 2 210-6558
luisrestrepoaramburo@gmail.com

Project Developer:
Green Gas
Miguel Delgado
Gerente de Proyectos
Palm Beach, Florida, USA
Phone: +1 561 676-9890
miguel.delgado@greengas.net

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CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: ELECTRICITY GENERATION

NEJAPA LANDFILL ♦ NEJAPA ♦ EL SALVADOR

The Nejapa Landfill receives municipal solid waste (MSW) from the San Salvador Metropolitan Area through a 20-year agreement with **MIDES S.E.M. de CV (MIDES)**, the owner and operator of the landfill. From 1999 through June 2005, roughly 2.7 million tonnes of MSW was disposed at the Nejapa Landfill, and this tonnage is expected to increase to 12.5 million tonnes by 2024. Environmental impact, health, and safety issues for the population, as well as energy potential, led the project developer and former owner, **Biothermica Energie Inc. (Biothermica)**, to conduct a feasibility study at the site to minimize these impacts and assess the potential for developing a landfill gas (LFG) energy facility. In 2005, Biothermica entered into an agreement with MIDES for project development, financing, construction, and operation of the LFG collection system, flaring station, and power plant under the **Clean Development Mechanism (CDM)**.

In September 2005, Biothermica completed the first step for project registration under the CDM by obtaining national approval from the host country, El Salvador. Approval from the investment country, Canada, was obtained in November 2005. In December 2005, the project's validation process was completed by **Det Norske Veritas (DNV)**. Project registration by the **United Nations Framework Convention on Climate Change (UNFCCC)** was granted on 12 March 2006. Biothermica started construction of the LFG collection system and flaring station in February 2006. In March 2008, Biothermica sold the project to **AES Nejapa Gas Ltda (AES Nejapa)**, a subsidiary of AES Corporation. AES Nejapa has expanded the LFG collection system in response to increased LFG production. AES Nejapa developed a 6-megawatt (MW) power plant that went on line in May 2011 and has the potential capacity to expand to 24 MW in future years.

Information on this project can be found on the UNFCCC website at: http://cdm.unfccc.int/Projects/DB/DNV-CUK1134486361.05/view, Project No. 0167: "*Landfill Gas to Energy Facility at the Nejapa Landfill Site, El Salvador.*"

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1999
Closure Year (expected)	2024
Total Waste in Place (Mg)	6 million
Total Landfill Capacity (Mg)	12.5 million
Total Waste Footprint (ha)	80
Landfill Gas Energy Project	
Project Type	Electricity Generation
System Start Up	June 2006
Extraction Wells	134 vertical wells
Average Gas Flow in 2010 (m^3/hr)	3,100 at 48% CH_4
Emission Reduction in 2010 (tonnes CO_2e)	196,000
Project Capital Cost – LFG Collection System, LFG Rights, Distribution Grid update and 6-MW Power Plant (estimated, USD)	$58 million

Nejapa Facility

Nejapa LFG Collection System

Global Methane Initiative

Environmental Benefits

- Project has reduced emissions by 753,560 tonnes of carbon dioxide equivalent (CO_2e) emissions from 2006 to 2010.
- Contributes to sustainable development in El Salvador.
- Mitigates odors, fire issues, and LFG migration in surrounding neighborhoods.

Social Benefits

- Generates management, operation and maintenance opportunities associated with the project.
- Improves environmental and health-related conditions.
- Creates opportunities for socioeconomic development through technological transfer and collaboration with MIDES.
- Contributes to the reduction of dependency on fossil fuel.
- Promotes replication of similar projects to other landfill owners, project developers, and energy companies in El Salvador and Central America.

Past Barriers

- Financial analysis of the LFG energy project revealed that, without the Certified Emission Reduction (CER) revenue contribution, the project was not economically feasible.
- In the absence of regulations related to emissions from landfills in El Salvador, venting remains the most economically attractive means to control LFG.

Additional Information

- The project was developed in two phases: Phase 1 involved design, construction, and operation of the LFG collection and flaring system; Phase 2 involved design, construction, and operation of an LFG electricity system.
- Acquisition cost includes all capital cost, LFG rights, 6-MW power plant, interconnection and distribution grid update.
- The CDM registration cost for the project was $20,000 (USD).

Contact Information

Project Developer and Owner:

AES El Salvador / AES Nejapa Gas Ltda.
Luis Perez
Plant Manager
San Salvador/El Salvador
Phone: +503 2529-9627
luis.perez@aes.com

Global Methane Initiative
CASE STUDY

LANDFILL GAS PROJECT
PROJECT TYPE: FLARE WITH TRANSITION TO ELECTRICITY GENERATION

EL VERDE LANDFILL ♦ LEÓN ♦ GUANAJUATO ♦ MEXICO

Promotora Ambiental S.A.B. de C.V. (PASA) is a private waste collection and disposal firm in Mexico and is the owner and operator of the **El Verde Landfill.** The plan for the El Verde Landfill Gas (LFG) Project is to capture LFG, use part of it to evaporate leachate, and initially flare the remaining gas. Once LFG capture is established and the volume of LFG captured is known, three 0.8 megawatt (MW) engines will be installed to generate electricity. PASA contracted **MGM International** to prepare a project design document related to capturing and using landfill gas under the **Clean Development Mechanism (CDM)**.

Construction for the LFG capture, leachate evaporations, and flaring systems began in January 2009 and was completed in late 2009. In March 2009, PASA completed the first step for project registration under the CDM process by obtaining national approval from the host and investment country, Mexico. In October 2010, the project's validation process was completed by **SGS United Kingdom Limited**. Project registration by the **United Nations Framework Convention on Climate Change (UNFCCC)** was granted on 27 October 2010.

Information on this project can be found on the UNFCCC website at: http://cdm.unfccc.int/Projects/DB/SGS-UKL1265732335.87/Review, Project No. 3378: "*Landfill Gas Recovery and Flaring Project in the El Verde Landfill in Leon.*"

PROJECT SUMMARY

General Landfill Facts	El Verde Landfill
Opening Year	2001
Closure Year	2017
Total Landfill Capacity (Mg)	8.5 million
Total Waste Footprint (Ha)	60
Current Waste Footprint (Ha)	30
Total Waste in Place in 2007 (Mg)	2.9 million
Landfill Gas Project	
Project Type	Flare with Transition to Electricity Generation
System Start Up	Late 2009
Extraction Wells	48 vertical wells
Blower/Flare Station (m^3/hr)	1,869
Estimated Average Gas Flow (m3/hr)	509 at 50% CH_4
Average LFG Flow to the Evaporator (m3/hr)	310
Total Emission Reduction Annual Avg. (tonnes of CO_2e)	178,901
Project Capital Cost (USD)	$1.2 million

Aerial View of El Verde Landfill


Leachate Evaporator at El Verde


Blower/Flare Station

Environmental Benefits

- Projected to reduce an average of approximately 178,901 tons of carbon dioxide equivalent (CO_2e) annually.
- Mitigates odors and landfill gas migration in surrounding neighborhoods.
- Mitigates risk of explosions and slope stability.
- Reduces leachate contamination and methane emissions.
- Minimizes air pollution, including non-methane hydrocarbons.

Social Benefits

- Generates work opportunities associated with construction and operation and maintenance of the project.
- Promotes technology transfer with design, equipment and installations complying with international standards with regard to quality, reliability, operational safety and environmental aspects.

Project Barriers

- The advanced processes for treatment of solid waste require large investments and high operating costs compared with landfilling. With limited experience with these alternative processes in Mexico, the proposed CDM project relies heavily on technology transfer and CDM support.
- Substantial investments are required for capturing LFG, operating and maintenance, leachate evaporation, and technical equipment; if it had not been registered under CDM, the project would not be financially feasible.
- PASA had to ensure the LFG met the specifications and guidelines of environmental protection of both international and Mexico regulations. Mexico regulations are not always implemented, nor do they specify minimum requirements regarding the amount of gas to be collected and used or flared.

Additional Information

- Provides education and resources for research. PASA has an agreement with the Universidad de Nuevo León and the Fundación Mundo Sustentable (Sustainable World Foundation) to develop a course on climate change.
- The CDM registration cost for this project was $32,280 (USD).

Contact Information

Project Management:

Promotora Ambiental S.A.B. de C.V. (PASA)

Dr. Alfonso Martinez Muñoz
R&D Manager
Leon, Guanajuato, Mexico
Phone: +52 8113664637
E-mail: amartinezm@pasa.mx

Ricardo Lopez
Landfills Manager of Promotora Ambiental
Phone: +52 8113664628
E-mail: rlopezlo@pasa.mx

Global Methane Initiative

CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: PIPELINE-QUALITY GAS

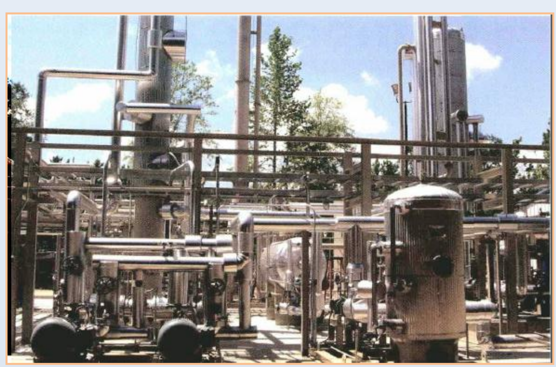
GREENWOOD FARMS LANDFILL ♦ TEXAS ♦ USA

The **Greenwood Farms Landfill** is located in the U.S. State of Texas and is owned by the **City of Tyler**. The City of Tyler and landfill operator **Republic Services, Inc.,** partnered with project developer **Morrow Renewables, LLC,** to build a "pipeline-quality gas" project. Within 9 months, Morrow constructed the landfill gas (LFG) collection system, gas treatment plant and pipeline. The gas treatment plant has been cleaning and treating LFG for sale into the Gulf South Pipeline since early 2009. The project uses the latest advancements in technology to remove carbon dioxide, water vapor, hydrogen sulfide and other impurities. The pipeline-quality gas that results is composed of more than 95 percent methane with a heating value similar to natural gas. Hence, the landfill can capitalize on higher gas prices even with low LFG flow rates. The captured LFG, which was previously flared, is now used to heat homes and businesses.

Information on this project can be found on the U.S. Environmental Protection Agency (EPA) Landfill Methane Outreach Program (LMOP) website at: http://www.epa.gov/lmop/projects-candidates/profiles/greenwoodfarms.html.

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1989
Closure Year (expected)	2020
Total Waste in Place (Mg)	5.0 million
Total Landfill Capacity (Mg)	67.0 million
Current Waste Footprint (ha)	33
Total Waste Footprint (ha)	81
Landfill Gas Energy Project	
Project Type	Pipeline-quality Gas
System Start Up	April 2009
Extraction Wells	60 vertical wells
Average Gas Flow (m^3/hr)	2,718
Average Emission Reduction (tonnes CO_2e/year)	189,000



Greenwood Farms Landfill

Environmental Benefits

- Reduces an average of approximately 189,000 tonnes of carbon dioxide equivalent (CO_2e) emissions annually.
- The landfill truck fleet is powered by an on-site compressed natural gas (CNG) refueling station. Morrow is voluntarily minimizing the negative impacts of greenhouse gases at this site, which does not require review under EPA's federal "new source performance standards."

Social Benefits

- Generates employment opportunities associated with construction, operation, and maintenance of the project.
- Yields annual energy savings that equate to heating 5,400 homes.

Past Barriers

- A major barrier to widespread commercial use of LFG is reliable, economically sound removal of contaminants in the recovered gas. In past years, it was not feasible to develop pipeline-quality gas recovery projects, which require a much higher standard of purification to make the LFG pipeline-ready. LFG recovery and plant operation models historically followed the LFG electricity model for this reason, using much less refined LFG to power motors and a conversion system that would produce electricity for sale to the grid, usually with more opportunity to benefit local power consumption needs. This business model produces a larger carbon footprint than the pipeline-quality gas model, but nevertheless has some appeal to communities that can benefit more directly when LFG is converted to a local source of electricity. However, recent advancements in LFG purifying technology have reduced costs, making the production of LFG for pipeline transport not only a more profitable long-term venture, but a cleaner one as well. The Greenwood Farms LFG energy project is an example of community mindset evolving to embrace greater investments in pipeline-quality LFG recovery as an environmental tool.

Additional Information

- The cleaned and treated LFG is being sold into the Gulf South Pipeline.

Contact Information

Project Management:
City of Tyler
Dan Brotton
Solid Waste Director
414 N. Bois D'Arc Avenue
Tyler, TX 75702
Phone: +1 903-531-1388

Project Developer:
Morrow Renewables, LLC
Luke Morrow
President
P.O. Box 60480
Midland, TX 79711
www.southtexrenewables.com

CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: DIRECT USE

STAR RIDGE LANDFILL ♦ ALABAMA ♦ USA

The **Star Ridge Landfill** is located in the U.S. State of Alabama and is owned by **Veolia Environmental Services (ES)**. **Jenkins Brick Company**, headquartered in Montgomery, Alabama, built a new manufacturing facility (the Jordan Plant) next to the landfill, with the goal of utilizing the landfill gas (LFG) as fuel for the plant. Jenkins Brick Company chose this location for the manufacturing plant based on a study conducted by its consultant, **CH2M HILL**, in 2003 and 2004, as well other criteria such as proximity to high-quality feedstocks, railroad systems and other business considerations. A contract was signed between Jenkins Brick Company and the landfill owner in November 2004. The LFG energy component of the project was self-developed by the Jenkins Brick Company, while CH2M HILL designed the 9.6-kilometer pipeline system and supervised its installation. The new manufacturing plant was opened in October 2006.

Information on this project can be found on the U.S. Environmental Protection Agency (EPA) Landfill Methane Outreach Program (LMOP) website at: http://www.epa.gov/lmop/projects-candidates/profiles/jenkinsbrickjordanplantla.html.

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1982
Closure Year (expected)	2060
Total Waste in Place in 2009 (Mg)	2.3 million
Total Landfill Capacity (Mg)	35.9 million
Total Waste Footprint (ha)	15.8
Landfill Gas Energy Project	
Project Type	Direct Use
System Start Up	January 2007
Extraction Wells	33 vertical wells 3 horizontal wells
Average Gas Flow (m^3/hr)	1,274 at 53% CH_4
Average Emission Reduction (tonnes CO_2e/year)	88,500
Project Capital Cost (USD)	$4 million

Star Ridge Landfill and Jenkins Bricks

Environmental Benefits

- Reduces demand for – and emissions from – fossil fuel use.
- Nearly 40 percent of the manufacturing plant's energy requirements are currently met by the produced LFG, and this level is projected to grow to 100 percent over 10 years, reducing the need for electricity from sources operating on fossil fuel.

Social Benefits

- The brick manufacturing facility is the largest one ever built at one time in the United States and was instrumental in generating new jobs in a rural area of Alabama.
- Uses an otherwise wasted alternative energy source, which saves money.

Past Barriers

- Jenkins worked creatively as it sought ways to avoid potential impacts to the Upper Cahaba River Watershed. The watershed is near the landfill, and the new plant could have been located within the watershed. Jenkins proactively pursued locating property outside of the watershed, even though it necessitated construction of an expensive 9.6-kilometer pipeline.

Additional Information

- This project is the first instance in the United States of a manufacturing facility that is built next to a landfill specifically for the purpose of using LFG as fuel. In 2004, as a result of demand for its products, Jenkins decided to expand its output and set about to do so with a site evaluation and selection process that had a landfill energy source as its core strategy. Jenkins evaluated hundreds of existing landfills in eight states. The evaluation included a review of the landfills, an assessment of the economic considerations for each prospective landfill, identification of the brick kiln fuel needs, an evaluation of the landfill's existing gas collection systems, and a projection of the future LFG supply for each landfill.
- Jenkins Brick Company was awarded LMOP's Project of the Year in 2006 and the Alabama Governor's Conservation Achievement Award for Air Conservationist of the Year in 1999 and 2007.

Contact Information

Project Management:
Veolia ES Star Ridge Landfill
Scott Corley, Area Manager
Moody, AL
Phone: 205-640-1799

Project Developer and End User:
Jenkins Brick Company
Mike Jenkins V
Vice President, Production
201 N. Sixth Street
Montgomery, AL 36104
Phone: 334-834-2210
mike.jenkins@jenkinsbrick.com

Global Methane Initiative

CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: DIRECT USE

YANCEY-MITCHELL COUNTY LANDFILL ♦ NORTH CAROLINA ♦ USA

The **Yancey-Mitchell County Landfill** is located in the U.S. State of North Carolina and is managed by **Yancey County**. The landfill is located in a rural area and is home to unique native plants. When the landfill closed in 1994, three organizations — **Blue Ridge Resource Conservation and Development Council (BRRC&D)**, **HandMade in America (HandMade)** and **Mayland Community College (MCC)** — teamed together to design and develop the landfill gas energy (LFGE) project and the EnergyXchange Renewable Energy Center at the landfill.

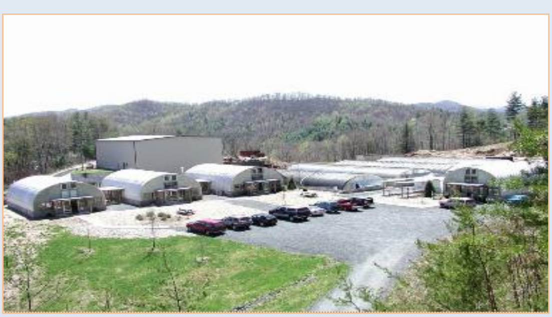
In 1996, BRRC&D, a local branch of the U.S. Department of Agriculture, began to research new ways to capture and use LFG. With the help of a feasibility study conducted by the U.S. Environmental Protection Agency (EPA) Landfill Methane Outreach Program (LMOP), it was determined that the quality of LFG at this landfill was sufficient for use as an energy source. The captured heat energy is now being used to run pottery kilns and glass blowers, in addition to supplying radiant heat for a greenhouse and other buildings located at the landfill. HandMade and MCC provided the resources necessary to set up facilities at the landfill for local pottery artists and horticulturists. The system was commissioned in April 1999, and the EnergyXchange Renewable Energy Center opened for business in 2001.

Information on this project can be found on the LMOP website at:
http://www.epa.gov/lmop/projects-candidates/profiles/energyxchangerenewableene.html.

More information on the EnergyXchange Renewable Energy Center can be found at: http://www.energyxchange.org/.

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1973
Closure Year	1994
Total Waste in Place (Mg)	0.35 million
Total Waste Footprint (ha)	2.4
Landfill Gas Energy Project	
Project Type	Direct Use
System Start Up	April 1999
Extraction Wells	8 vertical wells 2 horizontal wells
Average Gas Flow (m^3/hr)	60 at 50% CH_4
Average Emission Reduction (tonnes CO_2e/year)	4,000
Project Capital Cost (estimated, USD)	$2 million


EnergyXchange Renewable Energy Center


Greenhouse


Glass Studio

Environmental Benefits

- Reduces an average of approximately 4,000 tonnes of carbon dioxide equivalent (CO_2e) emissions annually.
- Reduces local smog.

Social Benefits

- This project has demonstrated the power of partnerships and has become a model for other projects regionally, nationally, and internationally.
- The LFG energy project has generated work opportunities associated with construction, operation and maintenance of the project, including creation of three permanent jobs.
- In the greenhouse, boilers are heated using the captured LFG and waste wood to grow native plants from seed for sale to local plant wholesalers. Visitors learn innovative ways to propagate and preserve rare, native flora. The area is now home to 15 new native plant businesses.
- In the craft studios, local artisans use kilns and glass furnaces heated using the captured LFG, to create art that is sold at the on-site craft gallery. The artists pay a nominal fee to use the facilities but have saved a total of approximately $1 million during the first 10 years of the project's operation, when compared with the use of traditional fuel sources.
- Two new glass businesses and five new pottery businesses have opened in the area.

Past Barriers

- In the past, the Yancey-Mitchell County Landfill was considered to be too small to be commercially viable. However, this LFG capture and use project has illustrated that LFGE projects at small landfills can be successful.

Additional Information

- The EnergyXchange Renewable Energy Center includes four greenhouses, three cold frames, a retail craft gallery, a visitor center, and clay and glass studios.
- This LFG energy project was awarded LMOP's Community Partner of the Year award in 1999.
- The EnergyXchange recently added a pallet-fired pottery kiln to utilize another wasted fuel resource.
- The EnergyXchange recently completed a major facility renovation and added new boilers.

Contact Information

EnergyXchange
66 EnergyXchange Drive
Burnsville, NC 28714
Phone: 828-675-5541
info@energyxchange.org

CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: ELECTRICITY GENERATION

BARYCZ LANDFILL ♦ KRAKOW ♦ POLAND

The **Barycz Landfill** is located in Krakow, Poland, and is owned by the **Kraków Municipal Cleaning Company Ltd. (MPO Sp. z. o.o.).** The landfill was developed in three phases: the first two phases are closed, and the landfill is now operating in its third phase.

The landfill gas (LFG) collection and utilization project was primarily financed by the landfill owner and operator as well as the **Instrument for Structural Policies for Pre-Accession (ISPA)/Cohesion Fund**. Before construction began, the **Polish Academy of Science** conducted a feasibility study at the landfill and suggested a design for the LFG collection system. The blower and flare station were built in 1994 and four internal combustion engines were installed, one each in 1998, 1999, 2002 and 2008. The combined generating capacity of these engines is 1.3 megawatts (MW) with an average output of 1.0 MW. Currently, about 600 cubic meters per hour (m^3/hr) of LFG with a methane content of 55 percent is produced from more than 3.4 million megagrams (Mg) of waste at the site. The landfill sells not only the electricity, but also the associated Green Certificates, which produce 280 Polish Zloty (approximately $80 USD)/megawatt-hour) in addition to the conventional electricity price.

Information on this project can be found on the MPO and GMI websites at:
http://www.mpo.krakow.pl and http://www.globalmethane.org/documents/events_land_101411_tech_klimek.pdf.

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1974
Closure Year (expected)	2016
Total Waste in Place in 2002 (Mg)	3.4 million
Total Landfill Capacity (Mg)	4.2 million
Current Waste Footprint (ha)	10.8
Total Waste Footprint (ha)	36
Landfill Gas Energy Project	
Project Type	Electricity Generation
System Start Up	May 1998
Extraction Wells	70 vertical wells
Monitoring Manifolds	1
Blower/Flare Station Capacity (m^3/hr)	1,000
Average Gas Flow (m^3/hr)	600 at 55% CH_4
Average Emission Reduction (tonnes CO_2e/year)	55,000

Engines at Barycz Landfill

Environmental Benefits

- Reduces an average of approximately 55,000 tonnes of carbon dioxide equivalent (CO_2e) emissions annually.
- Mitigates odors that had been the subject of complaints by residents in surrounding neighborhoods.

Social Benefits

- The response to the project from the press and the public has been positive.

Past Barriers

- The distance between the pump and flare system and the LFG utilization system was large and required an extensive network of pipelines.
- The horizontal extraction pipelines have flooded with water on occasion; future plans include installation of only vertical wells.
- Some equipment was acquired from Germany, making operation and maintenance expensive. Local equipment manufacturers will be used in the future at this landfill.

Additional Information

- The waste heat from the engines is being used to heat buildings at the landfill.
- A composting facility at the site became operational in 2005; it has a capacity of 6,000 tonnes per year. At this facility, MPO composts only green waste from parks and gardens to make the process safer and ensure high-compost quality. The compost is used at the Barycz Landfill and is also sold externally.
- The sorting plant became operational in 2006 and can sort approximately 20,000 tonnes of waste per year.

Contact Information

Krystyna Flak
Miejskie Przedsiebiorstwo Oczyszczania Sp. z o.o.
31-580 Kraków
1 Nowohucka Street
Phone: 012 646 22 02
utylizacja@mpo.krakow.pl

Global Methane Initiative

CASE STUDY

LANDFILL GAS PROJECT
PROJECT TYPE: FLARE WITH TRANSITION TO ELECTRICITY GENERATION

CLOSED MARIUPOL LANDFILL ♦ MARIUPOL ♦ UKRAINE

The **Closed Mariupol Landfill** is located in the City of Mariupol, Ukraine, and is owned by the **Mariupol City State Administration**. The landfill is located in a mixed-use area with residential, agricultural, commercial and industrial uses. Until its closure in 2008, the landfill accepted domestic and commercial waste from the City of Mariupol. During its active phase, certain landfill management practices led to significant leachate production, storm water runoff, and unintended fires. Post-closure, the landfill accepts only soil and some construction and demolition debris.

In August and September 2008, the U.S. Environmental Protection Agency (EPA) Landfill Methane Outreach Program (LMOP), as part of the Global Methane Initiative (GMI), conducted pump tests at this landfill. The pump tests yielded a landfill gas (LFG) recovery rate capable of supporting a flare or electricity project. In February 2009, the Mariupol City Council awarded the LFG capture and utilization project at two of the city's landfills to **TIS Eco Company**. TIS Eco Company, in partnership with **Scientific Engineering Center (SEC) Biomass**, began construction at the Closed Mariupol Landfill in June 2009. The system was commissioned in February 2010. In August 2010, the **National Environmental Investment Agency** issued a Letter of Approval to the *"Collection and recycling of methane from solid waste landfills, Mariupol, Ukraine"* for a **Joint Implementation (JI)** project.

Information on this project can be found on the GMI website and the UNFCCC JI website at:
http://www.globalmethane.org/activities/actSiteDetailsForLandfill.aspx?myObjId=a09A0000004vISCIA2 and
http://ji.unfccc.int/JIITLProject/DB/ZEVLVPNJNVYMFSATZCZ1ARDFO2JTY7/details.

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1967
Closure Year	2008
Total Waste in Place (Mg)	2.1 million
Total Waste Footprint (ha)	12.3
Landfill Gas Project	
Project Type	Flare with Transition to Electricity Generation
System Start Up	February 2010
Extraction Wells	43 vertical wells
Monitoring Manifolds	3
Blower/Flare Station Capacity (m^3/hr)	160-800
Average Gas Flow in 2010 (m^3/hr)	390 at 50% CH_4
Average Emission Reduction (tonnes CO_2e/year)	40,000-75,000
Project Capital Cost – Collection and Flaring System (estimated, USD)	$867,000

Pipeline Installation

LFG Collection Well

LFG Flare

Environmental Benefits

- Expected to reduce 40,000 to 75,000 tonnes of carbon dioxide equivalent (CO_2e) emissions annually.
- Mitigates odors and LFG migration in surrounding neighborhoods.
- Minimizes air pollution by eliminating emissions of hazardous organic compounds and other pollutants.
- Improves slope stability and mitigates fires issues.
- Helps with leachate management by reducing its quantity and toxicity.

Social Benefits

- Generates employment opportunities associated with construction, operation, and maintenance of the project.

Past Barriers

- Ukrainian landfills are relatively small, and the lack of reliable technical data and financial assistance from local municipalities makes project implementation challenging. To overcome these barriers, GMI has been providing technical assistance on an as-needed basis and facilitated the identification of private investors at the Project Expo held in 2010 in New Delhi, India.

Additional Information

- The LFG collected is being directed to a cogeneration plant, where up to 1.25 megawatts of electricity are expected to be generated and supplied to a distribution network. Some of the electricity produced will also offset the needs of the LFG collection and distribution system. Heat energy generated at the plant will provide an alternative energy source for a nearby greenhouse and brick manufacturing facility using an infrared heater or a kiln. Any surplus LFG will be flared.
- The LFG collection system and cogeneration plant are expected to function for up to 15 years.
- The JI registration cost for the project was $20,000 (USD).

Contact Information

Project Management:
Mariupol City Council
Yuri Khotlubey
Mayor
87500, Ukraine, Donetsk Region
Mariupol, 70 Lenina Ave
Phone: +38 (0629) 33-22-40
gorsovet@marsovet.org.ua

Project Developer:
TIS Eco Company
Victor Savkiv
President, TIS Group Companies
01862, Ukraine, Kyiv Region
Chabany, vul. Mashinobudivnikiv, 1
Phone: +38 (044) 251-05-81, 82, 83
vsavkiv@tiseco.com.ua

Global Methane Initiative

CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: ELECTRICITY GENERATION & DIRECT USE

GAOANTUN LANDFILL ♦ BEIJING ♦ CHINA

Gaoantun Landfill is a sanitary landfill owned and operated by the **Beijing Chaoyang District Garbage Innocent Disposal Center (CDGIDC)**. In February 2007, the **U.S. Environmental Protection Agency (EPA)** met with municipal officials to evaluate the potential to expand use of landfill gas (LFG) at this site. The site was selected for a pump test evaluation. Later that year, EPA conducted the pump test and produced a pre-feasibility study about the technical viability of producing additional LFG energy at the site. Currently, LFG from the landfill is used to generate electricity from three 500-kilowatt (kW) and one 1,000 kW reciprocating engines and to fuel a 700-kW boiler. The boiler operates 24 hours per day in the winter and 3 to 4 hours per day during the other seasons; the total generating capacity is 2.5 megawatts (MW). CDGIDC plans to ultimately increase the power generating capacity to 5 MW.

Information on this project can be found on the GMI website at:
http://www.globalmethane.org/activities/actSiteDetailsForLandfill.aspx?myObjId=a09A0000004vIJoIAM.

PROJECT SUMMARY

General Landfill Facts	
Opening Year	2002
Closure Year (expected)	2022
Total Waste in Place in 2007 (Mg)	4.19 million
Total Landfill Capacity (Mg)	8.0 million
Current Waste Footprint (ha)	30
Landfill Gas Energy Project	
Project Type	Electricity Generation and Direct Use
System Start Up	2007
Extraction Wells	150 vertical wells
Monitoring Manifolds	5
Average Gas Flow in 2011 (m^3/hr)	2,500 at 60% CH_4
Current Average Emission Reduction (tonnes CO_2e/year)	34,000

Aerial View of Gaoantun Landfill

Typical Gas Well at Gaoantun Landfill

Environmental Benefits

- When fully implemented, the project is estimated to reduce a total of 306,000 tonnes of carbon dioxide equivalent (CO_2e) emissions from electricity generation and 213,000 tonnes of CO_2e through direct use for the period 2008 through 2022.
- Mitigates odors and LFG migration in surrounding neighborhoods.
- Offsets the use of fossil fuels.

Social Benefits

- Provides revenue from the sale of unused electricity to the local power grid or the sale of Certified Emission Reductions (CERs).
- Provides thermal energy for industrial or agricultural use.

Past Barriers

- As a result of problems at nearby landfills, the actual waste inflow to Gaoantun Landfill has been higher than originally designed, and the landfill's capacity would be exhausted before the expected closure year of 2022.
- Whether a direct-use project at the solid waste or medical incinerator is economically feasible depends on the cost of retrofitting the incinerator for gas use and how much the potential user is willing to pay for energy.

Additional Information

- Prior to EPA's assessment, the landfill installed a 500-kW reciprocating engine generator to generate electricity for consumption by the on-site leachate treatment plant.
- Gas is still being flared at the site, so investment opportunities exist for productive uses of this gas. Furthermore, in addition to the energy used on site, energy will be available to sell to potential users near the landfill.
- Gas generation and recovery at the site have been reduced as a result of decline in raw waste intake, a trend that began in 2009 and is continuing because of Beijing's policy to completely ban landfilling of raw waste by 2012. As a result, since 2009, increasing amounts of daily raw waste accepted have been diverted to an adjacent incinerator.

Contact Information

Beijing Chaoyang District Garbage Innocent Disposal Center
Mr. Zhang Quanhong
Beijing, China
Phone: +86 10 6541 7383
ZQH70226@sohu.com

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CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: DIRECT USE

JIAOZISHAN LANDFILL ♦ NANJING CITY ♦ CHINA

The Jiaozishan Landfill is located in Nanjing City, China, and is owned by **Nanjing Yunsheng New Energy Development Company, Limited (NYNED)**. The landfill is located in a rural area and consists of three storage areas: areas 1 and 2 are being used for this landfill gas (LFG) recovery and utilization project, while area 3 has been closed and exhaust vents direct its LFG to the atmosphere.

In August 2006, the host country, China, approved the LFG recovery and utilization project at Jiaozishan Landfill, and registration under the **Clean Development Mechanism (CDM)** was initiated. In April 2007, CDM consultant **CAMCO International Limited** facilitated the project's validation process through **SGS United Kingdom Limited** of the United Kingdom. The project was registered by the **United Nations Framework Convention on Climate Change (UNFCCC)** on 30 November 2007 and approved in August 2009. NYNED started construction in October 2005 and installed two sets of boiler systems and a flare. The flare destroys excess LFG when boiler load is low or they are out of service for maintenance. The boilers were commissioned in May 2006 and began operating 2 months later. The flare began to operate in September 2010.

Information on this project can be found on the World Bank website at:
http://cdm.unfccc.int/Projects/DB/SGS-UKL1178631263.99/view, Project No. 1120: *"Jiaozishan Landfill Gas Recovery and Utilisation Project."*

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1992
Closure Year (expected)	2022
Total Waste in Place in 2005 (Mg)	2.8 million
Total Landfill Capacity (Mg)	5.5 million
Total Waste Footprint (ha)	28
Landfill Gas Energy Project	
Project Type	Direct Use
System Start Up	July 2006
Blower/Flare Station Capacity (m^3/hr)	2,000
Average Gas Flow (m^3/hr)	1,130 at 53% CH_4
Average Emission Reduction (tonnes CO_2e/year)	153,000

Equipment at Jiaozishan Landfill

Environmental Benefits

- Project reduces 153,000 tonnes of carbon dioxide equivalent (CO_2e) emissions annually.
- Provides a heat supply system for the city that will reduce its dependence on coal, oil or electricity.
- Mitigates odors and LFG migration in surrounding neighborhoods.
- Mitigates fire issues.

Social Benefits

- Demonstrates the use of new technologies obtained through international partnerships and facilitates technology transfer for other LFG management projects across China.
- Serves as a model for LFG management experience in China since it is one of the earliest LFG recovery projects initiated in the country.
- Generates work opportunities associated with construction, operation, and maintenance of the project.

Past Barriers

- This landfill is one of the earliest sanitary landfills established in China and is representative of a typical medium-sized landfill. Prior attempts to harvest LFG from landfills have not been economically viable. This project presents an opportunity to understand how to successfully collect and manage LFG for beneficial use.

Additional Information

- LFG is combusted in boilers to produce steam, which heats water through heat exchangers. Heat generated by the LFG is expected to be used to heat water for the use of nearby commercial establishments such as hotels and bathhouses. The hot water is trucked to customers in Nanjing City. This project is the first such direct-use application of LFG in China. The CDM project registration cost was $29,148.80 (USD).

Contact Information

Nanjing Yunsheng New Energy Development Co., Ltd
Li Jianping
Phone: +86 25 5274 1184

Global Methane Initiative

CASE STUDY

LANDFILL GAS ENERGY PROJECT
PROJECT TYPE: DIRECT USE

DAEGU-BANGCHEON-RI LANDFILL ♦ DAEGU ♦ REPUBLIC OF KOREA

The **Daegu-Bangcheon-Ri Landfill** is located in the southeastern part of Korea in Daegu City. The treatment of landfill gas (LFG) from Daegu Bangcheon-Ri Landfill was managed as "simple on-site treatment" to prevent odor, air pollution and fire before this project was installed. In 2004, **Taegu Energy & Environment Co. Ltd. (TEEC)** signed a Build-Operate-Transfer agreement with the **Daegu Metropolitan City (Daegu City)** to build and operate the landfill's gas capture and utilization project. TEEC also signed an agreement to supply the LFG to **Korea District Heating Corp (KDHC)** to produce thermal energy for businesses, apartments and commercial buildings in KDHC's service area. In January 2006, Daegu City announced that the Daegu-Bangcheon-Ri Landfill gas recovery project would be submitted as a **Clean Development Mechanism (CDM)** project.

In January 2005, TEEC started construction, which included installation of vertical LFG wells, a flare stack, a blower system, a refinery that includes filters and scrubbers, a generation facility and a gas storage tank. In January 2007, Daegu City completed the first step for project registration under the CDM by obtaining national approval from the host country, Korea. Approvals from the investment countries, Switzerland and the United Kingdom, followed. In May 2007, the project's validation process was completed by **Lloyd's Register Quality Assurance Limited (LRQA)**. Project registration to the **United Nations Framework Convention on Climate Change (UNFCCC)** was granted on 19 August 2007.

Information on this project can be found on the UNFCCC website at:
http://cdm.unfccc.int/Projects/DB/LRQA%20Ltd1168417374.37/view, Project No. 0851: "*Daegu Bangcheon-Ri Landfill CDM Project.*"

PROJECT SUMMARY

General Landfill Facts	
Opening Year	1990
Closure Year (expected)	2026
Total Waste in Place in 2009 (Mg)	14.7 million
Total Landfill Capacity (Mg)	24.8 million
Total Waste Footprint (ha)	59.7
Landfill Gas Energy Project	
Project Type	Direct Use
System Start Up	2006
Blower/Flare Station Capacity (m^3/hr)	150
Average Gas Flow in 2009 (m^3/hr)	5,400 at 48% CH_4
Emission Reduction in 2009 (tonnes CO_2e)	307,300
Project Capital Cost (estimated, USD)	$20 million

Aerial View of Daegu-Bangcheon-Ri Landfill

LFG Storage Tank

Environmental Benefits

- Reduced 307,300 tonnes of carbon dioxide equivalent (CO_2e) emissions in 2009.
- Mitigates odors, air pollution, and risk of explosion in surrounding areas.
- Mitigates climate change by controlling methane emissions to the atmosphere and replacing fossil fuels.

Social Benefits

- Contributes to sustainable development by providing an alternative energy source.
- Creates economic benefits for the local area by selling medium-quality gas.
- Provides financial benefits from the sale of the Certified Emission Reductions (CERs).

Past Barriers

- The successful completion of the CDM process led to the realization that the distribution of the CERs had not been adequately agreed on by the parties involved in the project. The issue was resolved through arbitration and led to the formation of the Korean Carbon Law Society to help in resolving carbon emission-related issues.

Additional Information

- The CDM registration cost for this project was $79,474 (USD).

Contact Information

Project Management:
Taegu Energy & Environment Co., Ltd
Dr. Suk-hyung Lee
President & CEO
Daegu, Republic of Korea
Phone: +82 52-593-1893
tkjung@teeco.co.kr

Project Developer:
Daegu Metropolitan City
Bum-il Kim
Mayor
Daegu, Republic of Korea
Phone: +82 53-803-4262
hskim@daegumail.net

Global Methane Initiative

International Best Practices Guide for Landfill Gas Energy Projects

Appendix B
Health and Safety Considerations

As with other industrial projects, there are risks to personnel and surrounding neighbors from construction and operation of an LFGE project. Following proper considerations for health and safety issues can greatly reduce these risks. An SWD site owner or project developer should thoroughly evaluate the health and safety aspects related to the project, ensure compliance with local and state health and safety regulations and develop site-specific plans to address these issues and promote safe and productive operation. These considerations include knowledge of hazard types, plans and procedures, equipment training and site security.

Types of Hazards

A variety of hazards are present at SWD sites and LFGE projects. Examples of common hazards include:

- ***LFG*** – LFG contains methane, which is explosive under certain conditions. Methane may also be an asphyxiant as it can displace oxygen in confined spaces. Smoking and other sources of ignition should be prohibited in areas with potential LFG emissions, and warning signs should be prominently posted. LFG may also contain hydrogen sulfide (H_2S), which may create a significant respiratory hazard for personnel.
- ***Construction/Drilling*** – Drilling and construction of a gas collection and control system (GCCS) can generate potential hazards ranging from falls, impacts, dust and hazards related to LFG and severe winds or weather.
- ***Chemical/Biological*** – Chemicals used at the site or the waste itself may present hazards. It is necessary to carefully follow instructions on chemicals, observe proper work rules and use personal protective equipment (PPE) when in contact with the waste.
- ***Natural*** – Personnel should be trained to recognize hazards posed by insects, animals and poisonous plants. A project hazard assessment should include these natural hazards. Note that natural hazards can vary greatly depending on geographic location.
- ***Confined Spaces*** – A confined space is either a completely enclosed or a partially enclosed space not primarily intended for personnel that has a restrictive entry or exit and can potentially contain hazards. Many hazards may be present, including a lack of oxygen as well as fire, extreme temperatures, chemical hazards, trip hazards, uncontrolled energy and potential methane travel (because it is lighter than air). Effort should be made to identify confined spaces at the site and develop the means to control confined space hazards and establish proper PPE requirements when personnel must work in them.

Plans and Procedures

Carefully developed plans and procedures can help ensure that health and safety considerations are addressed and well-positioned for improvement efforts. Clearly written and concise plans are important and enable personnel to avoid crisis situations by providing well-developed steps that promote a safety conscious approach to their jobs. In a crisis, decisions and actions must be made quickly and often on the basis of imperfect information. In these situations, clearly written and concise plans and procedures are of critical importance in allowing personnel to react quickly in a manner that promotes safety. Typical health and safety plans and procedures include the following:

1. ***Nearest Hospital*** – All project employees and officials should know where the nearest capable hospital is located and how to get there quickly. Receiving rapid medical attention is a significant factor in minimizing injury and recovery from serious accidents.

2. ***Emergency Procedures*** – Procedures that address emergencies must be clearly written, concise and easily accessible by all personnel. A key attribute of effective emergency procedures is prior knowledge. (Personnel should be thoroughly familiar and well-trained on the use of such procedures before ever using them.)
3. ***Site Hazards*** – SWD sites should perform a hazard assessment to identify the type and severity of hazards existing at a project site. Hazards may include sources of explosive methane, electric sources, sharp objects, machines or processes in motion, high temperatures, chemical exposure, falling objects and trip hazards. After a thorough and documented site assessment, risks associated with hazards should be mitigated through a variety of means — for example, revised plans and procedures, installation of special equipment and the selection of appropriate PPE.
4. ***Personal Protective Equipment*** – Although preventing a hazard or controlling it at the source is the most effective way to protect personnel, hazards can still exist and controls can fail. In these cases, PPE can protect personnel. Examples of PPE include hard hats, ear plugs, gloves and safety glasses.

Equipment Training

A typical LFG project may include equipment such as mobile machinery, blowers, compressors, flares, piping and aerial lifts. Each of these contains its own specific and different hazards (such as electric shock, kinetic energy, explosiveness or high noise). Improper or untrained use of this equipment can result in serious injury or death. To be operated safely, this equipment requires training on operation, potential hazards and knowledge of equipment-specific emergency procedures. Depending on the type of equipment, manufacturers may offer training programs.

Site Security

Site security involves protecting the SWD site from unauthorized entry and the safety of those seeking unauthorized entry. In addition to protecting site equipment from tampering by unauthorized personnel, site security can discourage public health risk and injuries from scavenging and prevent dumping of unwanted waste. Providing appropriate site security may involve installing and maintaining a durable and impervious perimeter fence and gates, stationing properly trained security guards, maintaining a visitor logbook, and displaying prominent signage to discourage unauthorized access.