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A Guide for Methane Mitigation Projects

Gas-to-Energy at Landfills and Open Dumps

DRAFT Version 2

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This document is a working draft being used by Country Study Program participants to develop methane mitigation projects. Users of this document and those implementing methane mitigation projects are encouraged to provide feedback. Please direct comments to:

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1. INTRODUCTION

THIS report provides guidance for developing programs for reducing methane emissions from landfills and large open dumps by recovering and utilizing landfill gas. Landfill gas is produced by the anaerobic decomposition of waste. Since landfill gas is about 50% methane, it is both a potent greenhouse gas and a valuable source of energy. As a result recovering and utilizing landfill gas presents an economically attractive option for reducing greenhouse emissions.

This document is directed toward program managers responsible for developing greenhouse gas (GHG) mitigation programs in developing countries and countries with economies in transition. By focusing on identifying and evaluating opportunities to reduce emissions, this report complements the guidance developed by the U.S. Country Studies Program and materials available from related efforts of the U.S. Environmental Protection Agency and others. Furthermore, as a guidance document for reducing methane emissions from landfills, this report will assist countries in fulfilling their commitments under the United Nations Framework Convention on Climate Change (UNFCCC).

Given the economic value of landfill gas as a fuel source and the potential availability of international donor funding, landfill gas recovery and utilization presents one of the most cost-effective option for reducing methane emissions.

The main goal of this report is to provide a step-by-step method for identifying and evaluating landfills and large open dumps that are promising candidates for emissions reductions through gas recovery and utilization. Those characteristics that make gas recovery technically and economically attractive are presented. Additionally, this report discusses how national policies affect the viability of landfill gas recovery projects and identifies what steps might be taken to encourage the development of this resource.

The remainder of this report is organized into the following five chapters:

2. **Overview of Landfill Methane Emissions and Emissions Reduction Opportunities:** This section provides a brief background on the topics of methane emissions and opportunities for emissions reductions from landfills and large open dumps.

3. **Identifying Opportunities to Reduce Methane Emissions:** This section describes a screening process by which the program managers can identify whether landfills and large open dumps in their countries present attractive options for reducing emissions.

4. **Preliminary Site Assessments:** This section presents the process for conducting preliminary site assessments for individual sites or representative facilities identified as being good candidates for gas recovery projects in Section 3. Based on this information, the program manager can begin to design an emissions reduction strategy.

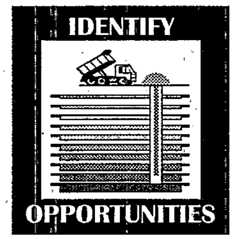
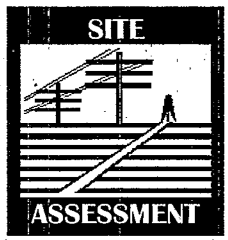
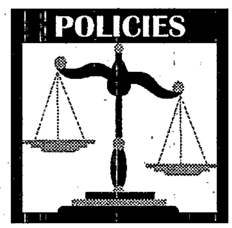
5. **Identifying and Assessing Key Government Policies:** This section identifies the key government policies that will promote or hinder

landfill gas recovery projects. Based on this information, potential policy options will be assessed in the context of national priorities.

6. **Next Steps:** This section discusses the steps that may be taken by program managers to further the development of an emissions reduction program for landfills and open dumps. Information on international funding sources for landfill gas recovery projects is presented in this section.

Exhibit 1-1 summarizes how this document can be used to meet various objectives. The first column lists several common objectives and the second column lists the chapter to consult and key elements of that chapter.

Exhibit 1-1: How to use this Document

Objective	Chapter to Consult
I WANT AN OVERVIEW OF METHANE AS A GREENHOUSE GAS • What are the sources of methane emissions and how does methane contribute to the greenhouse effect?	 **2. Overview Of Landfill Methane Emissions And Emissions Reduction Opportunities:** 2.1 Methane is a Potent Greenhouse Gas 2.2 Landfills are a Source of Methane Emissions 2.3 Approaches for Reducing Methane Emissions from Landfills and Large Open Dumps
SHOULD I TRY TO REDUCE METHANE EMISSIONS FROM LANDFILLS? • How do I assess whether we have landfills or open dumps that would be conducive to methane emissions reductions? • What data can I collect to identify promising opportunities to reduce methane emissions from landfills and open dumps?	 **3. Identify Opportunities For Reducing Methane Emissions** 3.1 Waste Management Practices 3.2 Use For Energy 3.3 "Large" Landfills and Open Dumps 3.4 Waste Characteristics 3.5 Initial Appraisal Results
I WANT TO ESTIMATE POTENTIAL EMISSIONS REDUCTIONS • How do I estimate the emissions reduction from individual gas recovery projects? • How do I estimate and compare costs and revenues from individual gas recovery projects? • How do I develop a national assessment of emissions reduction and energy production?	 **4. Preliminary Site Assessments** 4.1 General Site Information Required 4.2 Gas Recovery and Utilization Technologies 4.3 Economic Feasibility
WHAT POLICIES AND REGULATIONS ARE IMPORTANT? • What policies affect the economic viability of landfill gas recovery projects? • How can landfill gas recovery projects help meet other environmental goals? • What policies affect the availability of financing and technology?	 **5. Identify And Assess Key Government Policies** 5.1 National Energy Pricing, Subsidies, and Taxes 5.2 National Energy Supply Priorities 5.3 Environmental Goals 5.4 Financing 5.5 Technology Development
WHAT CAN I DO NEXT TO FACILITATE A PROJECT? • What additional studies are needed? • How do I remove the barriers that are slowing down the process? • Where can I get funding to undertake these activities?	 **6. Next Steps** 6.1 Focus on the Most Promising Projects 6.2 Availability of Technology and Expertise 6.3 Motivate Decisionmakers 6.4 Review Regulatory Framework 6.5 Obtain Project Funding
WHERE CAN I GET ADVICE FROM EXPERTS?	**Appendix A: Directory of Select Landfill Gas Recovery Experts in the U.S.**
WHAT ARE THE MAIN FUNDING SOURCES APPLICABLE TO LANDFILLS?	**Appendix B: Directory of Possible Funding Agencies**

2. OVERVIEW OF LANDFILL METHANE EMISSIONS AND EMISSIONS REDUCTION OPPORTUNITIES

THIS chapter provides a brief background to the topic of methane emissions and opportunities to reduction emissions from landfills and open dumps. First, background information is provided about the atmospheric importance of methane. Then methane emissions from landfills and large open dumps is discussed. Finally, the approaches for reducing methane emissions are presented.

2.1 Methane is a Potent Greenhouse Gas

Because methane is a source of energy as well as a greenhouse gas, reducing methane emissions from landfills and large open dumps is economically beneficial.

Methane (CH_4) is an important greenhouse gas and a major environmental pollutant. Methane is also the primary component of natural gas and as such can be a valuable energy source. Methane emissions reduction strategies offer one of the most effective means of mitigating global warming in the near term for the following reasons:

- **Methane (CH_4) is one of the principal greenhouse gases**, second only to carbon dioxide (CO_2) in its contribution to potential global warming. In fact, methane is responsible for roughly 18 percent of the total contribution in 1990 of all greenhouse gases to "radiative forcing," the measure used to determine the extent to which the atmosphere is trapping heat due to emissions of greenhouse gases. On a kilogram for kilogram basis, methane is a more potent greenhouse gas than CO_2 (about 21 times greater over a 100 year time frame).

- **Methane concentrations in the atmosphere have risen rapidly.** Atmospheric concentrations of methane have been increasing at about 0.6 percent per year (Steele et al. 1992) and have more than doubled over the last two centuries (IPCC 1990). In contrast, CO_2's atmospheric concentration is increasing at about 0.4 percent per year.

- **Reductions in methane emissions will produce substantial benefits in the short-run.** Methane has a shorter atmospheric lifetime than other greenhouse gases -- methane lasts around 11 years in the atmosphere, whereas CO_2 lasts about 120 years (IPCC 1992). Due to methane's high potency and short atmospheric lifetime, stabilization of methane emissions will have an immediate impact on mitigating potential climate change.

- **Because methane is a source of energy as well as a greenhouse gas, many emissions control options have additional economic benefits.** In many cases, methane that would otherwise be emitted to the atmosphere can be recovered and utilized or the quantity of methane produced can be significantly reduced through the use of cost-effective management methods. Therefore, emissions reduction strategies have the potential to be low cost, or even profitable. For example, methane recovered from landfills and open dumps can be used as an energy source.

- **Well demonstrated technologies are commercially available for reducing methane emissions.** For all of the major sources of anthropogenic methane emissions (except rice cultivation and biomass burning), cost effective methane reduction technologies are commercially available. While offering substantial emissions reductions and economic benefits, these technologies have not been implemented on a wide scale in the U.S. or globally because of financial, informational, legal, institutional, and other barriers.

The unique characteristics of methane emissions demonstrate the significance of promoting strategies to reduce the amount of methane discharged into the atmosphere.

2.2 Landfills are a Source of Methane Emissions

Methane is generated in landfills and large open dumps as a direct result of the natural decomposition of solid waste under anaerobic (in the absence of oxygen) conditions. The organic component of landfilled waste is broken down by bacteria in a complex biological process that produces methane, carbon dioxide,[1] and other trace gases. Estimates of global methane emissions from landfills and large open dumps range from 20 to 70 Tg/yr,[2] accounting for about six to twenty percent of total annual anthropogenic methane emissions (IPCC, 1992).

Landfills and large open dumps with at least one million tons of waste are typically suitable for gas collection and utilization. High levels of organic materials in the waste enhance the amount of gas that can be collected, and hence the emissions reduction that can be achieved.

Landfills are, by nature, heterogeneous - no two landfills are alike. Investigations into landfill microbial population characteristics have shown that there are considerable differences among landfills (Westlake, 1990). Nevertheless, there are a number of common factors that influence the generation of methane and its emission from landfills and large open dumps:

- **Waste Composition.** Methane is produced from the organic component of solid waste; therefore, a larger organic component increases the potential for methane generation.

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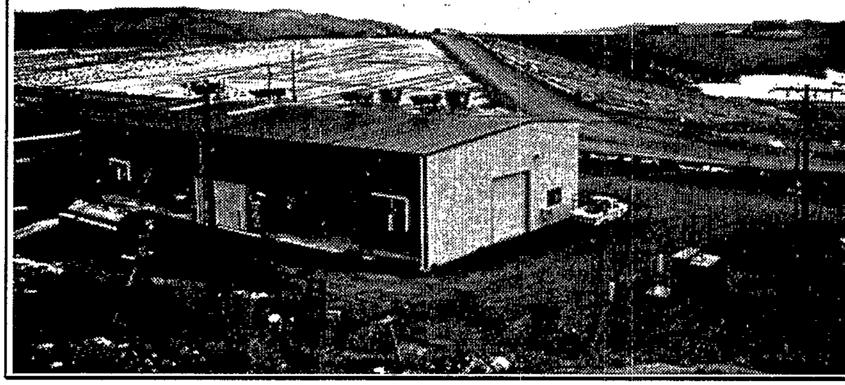
1 It should be noted that CO_2 emissions from landfills do not contribute to the increase in CO_2 abundance in the atmosphere because the carbon in the CO_2 is of recent biogenic origin (e.g., from crops and trees).

2 One teragram is 10^6 metric tons, or 10^{12} grams.

Exhibit 2-1: Typical Landfill Site



- **Anaerobic Environment.** In order to produce methane, organic material must break down in an anaerobic environment: i.e., in the absence of oxygen. The deliberate covering of solid waste with dirt in a landfill leads to the creation of anaerobic conditions. Similarly, the organic material in large open dumps becomes effectively covered by the other waste, thereby leading to anaerobic conditions and methane generation.

- **Moisture Content.** Moisture is essential for anaerobic decomposition (i.e., fermentation). Water provides the medium for cell growth and metabolism, and transportation of nutrients and bacteria within the landfill. The moisture content will depend on the initial moisture content of the waste, the extent of infiltration from surface and groundwater sources, and the amount of water produced as a result of waste decomposition.

- **Acidity.** Living systems are sensitive to pH (a measure of acidity); the optimal pH for methane production is between 6.8 and 7.2. Methane production decreases sharply with pH values below 6.5.

- **Temperature.** Methanogenic bacteria are affected by temperature; the rate of methane production is maximized between 50 and 60°C (120 to 140°F), but can occur anywhere from between 10 to 60°C (50 to 140°F) (Pacey and DeGier, 1986). Typically in landfills and large open dumps, the waste decomposition process provides enough heat maintain suitable temperatures for methanogenesis to take place.

In addition, the refuse density and consistency, the landfill design, and other site specific factors can affect the quantity and rate of methane generation.

EMISSIONS OVERVIEW

While there is considerable variation among landfills and large open dumps, facilities with at least one million tons[3] of waste are typically suitable for recovery. High levels of organic materials in the waste enhance the amount of gas that can be collected, and hence the emissions reduction that can be achieved. Under certain circumstances, smaller landfills have also been demonstrated capable of supporting profitable gas collection and utilization projects, particularly in areas where energy supplies are limited or prices are high.

2.3 Approaches for Reducing Methane Emissions from Landfills and Large Open Dumps

There are two main approaches for reducing methane emissions from landfills and large open dumps: (1) extract the gas through wells drilled into the waste, and then combust it; and (2) reduce the amount of organic waste entering landfills and large open dumps so that less methane is produced in the future. While activities such as recycling and/or composting reduce the amount of waste entering landfills (correspondingly reducing methane emissions), only the first approach--extracting and combusting the gas, reduces methane emissions from existing landfills and large open dumps which would otherwise continue to emit methane for many years to come. Additionally, even if some organic waste is prevented from entering landfills in the future, some waste will invariably be disposed in landfills, necessitating gas recovery and combustion as the most practical means of reducing emissions. Consequently, this document will focus on gas recovery and utilization to reduce methane emissions from landfills and large open dumps.

In addition to reducing methane emissions, recovering landfill gas has other important benefits: the gas can be used as an energy source; gas migration is reduced; local air quality is enhanced; and odor is reduced. These secondary benefits alone may warrant the installation of a gas recovery system.

By reducing emissions, landfill gas recovery projects fulfill a country's commitment to the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC requires developed countries (also known as Annex I countries) to adopt measures to reduce greenhouse emissions, with the aim of returning to 1990 emissions levels by the year 2000 (see Exhibit 2-2).

Additionally, the advantage of collecting gas from landfills and large open dumps is that the gas can be used as energy. Utilization options for the recovered gas include direct use in nearby residences or industrial facilities, injection into a pipeline grid, electricity generation, or steam production. Additionally, the gas can be flared, although flaring does not make use of the energy value of the gas.

- **Direct Gas Use.** Medium quality gas (e.g., 30 to 50 percent methane) can be used by local residences or industrial facilities as a boiler fuel or cooking fuel. Alternatively, the gas can be injected into a pipeline grid system. If the gas is delivered to a pipeline grid, it usually must be processed to achieve the requisite "pipeline quality" (i.e., en-

3 Tons are in metric units. This applies throughout the document.

Exhibit 2-2: The UN Framework Convention on Climate Change (UNFCCC)

The signature of the **United Nations Framework Convention on Climate Change (UNFCCC)** by around 150 countries in Riò de Janeiro in June 1992 indicated a widespread recognition that climate change is a potentially major threat to the world's environment and economic development.

The Convention aims to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level is to be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change. The Convention calls for Annex I countries to take measures designed to limit emissions of carbon dioxide dioxide and other greenhouse gases, with the aim of returning to 1990 emissions levels by the year 2000.

To achieve this objective, the Convention sets out a series of principles and general commitments. The key principles incorporated in the treaty are the precautionary principle, the common but differentiated responsibility of states (which assigns industrialized states the lead in combating climate change), and the importance of sustainable development. The general commitments, which apply to both developed and developing countries, are to adopt national programs for mitigating climate change; to develop adaptation strategies; to promote the sustainable management and conservation of greenhouse gas "sinks" (such as forests); to take climate change into account when setting relevant social, economic, and environmental policies; to cooperate in technical, scientific, and educational matters; and to promote scientific research and the exchange of information.

ergy value) which is usually the equivalent of almost 100 percent methane with minimal impurities.

- **Electricity Generation.** The recovered methane can be used to power an electric generator. The electricity can be used locally at nearby sites or delivered to the electricity grid system.
- **Steam Production.** Landfill gas can be used to produce steam which can be used for district heating or other uses.
- **Flaring.** A flare is simply a device for combusting the landfill gas. Capital requirements for flares are small relative to the energy recovery strategies, but the energy value of methane is wasted and therefore no revenue or other economic benefits are derived. Nevertheless, flaring may be an appropriate method for reducing emissions at small landfills, where the rate of gas flow will not support an economically viable gas recovery and utilization project.

In addition to producing energy with economic value, the recovery and combustion of gas environmental and safety benefits. Landfill gas contains volatile organic compounds which are major contributors to ground-level ozone formation. When no controls are in place, these pollutants are released into the atmosphere. When landfill gas is collected and burned in an energy recovery system, these pollutants are destroyed.[4]

[4] For this reason, the U.S. Environmental Protection Agency will issue New Source Performance Standards under the Clean Air Act in early 1996 which will require affected landfills to collect and combust their landfill gas.

Gas recovery also helps prevent underground gas migration. Migrating gas poses an extreme explosion hazard if it concentrates under nearby building or other facilities. Recovering the gas significantly reduces the risk of off-site migration.

Numerous methane recovery activities are currently in place around the world. There are many examples of profitable projects involving gas sales, electricity sales, or on-site use. However, many more landfills and open dumps can implement economically viable methane recovery and utilization projects. In some cases, national or local policies hinder these projects from being undertaken. Relevant policies should be evaluated to assess if they encourage or discourage methane recovery and utilization projects. Important issues to analyze include energy production and pricing, environmental policy, financing issues, and technology transfer policies.

2.4 References

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IPCC (Intergovernmental Panel on Climate Change) (1992). Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment, Published for the Intergovernmental Panel on Climate Change (IPCC), World Meteorological Organization/United Nations Environment Program. Cambridge University Press. Edited by J.T. Houghton, G.J. Jenkins, and J.J. Ephraums.

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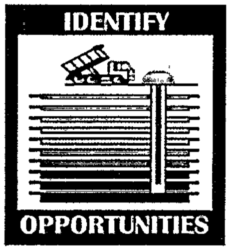

3. IDENTIFY OPPORTUNITIES FOR REDUCING METHANE EMISSIONS

THIS chapter presents a screening process for national program managers to determine if there are landfills or large open dumps in their countries that are good candidates for emissions reduction projects. This preliminary assessment of project opportunities consists of four phases: (1) determine whether there are landfills or large open dumps suitable for gas recovery; (2) determine whether there are potential markets for the energy recovered; (3) determine whether the landfills or open dumps must have enough waste to support a gas recovery project; and (4) determine whether the landfill contains sufficient organic waste.

A step-by-step approach is presented to assess whether opportunities for the implementation of gas recovery projects exist. Each step in the process is a hurdle to be crossed. If a hurdle cannot be crossed, it is unlikely that promising emissions reduction opportunities exist. For example, if there are no landfills or large open dumps, then there are no emissions reduction opportunities and the analysis ceases. Assuming that there are landfills, you may find that there can be no market for the gas recovered. In this case, gas recovery projects cannot be profitable, and emissions can only be reduced at a cost. In this case, the analysis would only proceed if the program manager is willing to consider emissions reduction options that cost money. In many countries, this step-by-step process is likely to identify large landfills and open dumps with potential for energy recovery resulting in emission reductions.

The initial screening criteria are as follows:

The first step in the screening process is to determine whether landfills or "large" open dumps exist in your country. Definitions of landfills and "large" open dumps are presented in Section 3.1.

1. **Existence of Landfills or Large Open Dumps Receiving Waste.** Wastes in developing countries and countries with economies in transition are disposed of primarily in open dumps and landfills. Only <u>landfills</u> and <u>large open dumps</u> may be considered candidates for gas recovery projects; small open dumps are not candidates. Therefore, only once the existence of large open dumps or landfills have been determined, can the analysis proceed. Section 3.1 presents a more detailed description of waste management practices, presenting the criteria to distinguish between landfills, large open dumps, and small open dumps.

2. **Existence of a Use for Energy.** An assessment of the potential to use the energy is essential to determine the potential profitability of gas recovery projects as well as to identify the most appropriate ways to use the gas. In general, any piece of equipment that uses natural gas as a fuel source potentially could be operated using landfill gas. Additionally, landfill gas can be used to power refuse collection trucks under some circumstances. Section 3.2 presents a simple checklist to determine whether there is potential to use the energy produced.

3. **Presence of "Large" Amounts of Waste.** For initial screening purposes, landfills containing more than 1 million tons of waste will be considered as potential candidates. Landfills of this size are likely to generate enough energy to support a recovery project. Section 3.3 presents several approaches to determine whether such landfills exist. It should be noted, however, that this size criterion is not absolute. Smaller landfills (e.g., over 500,000 tons of waste) could potentially support successful recovery projects, given certain site-specific and market conditions. These conditions are described in Section 3.6.

4. **Presence of Organic Materials in the Waste.** Since the organic component of waste is what produces gas, landfills with highly organic waste (e.g., food scraps, paper, and other biodegradable materials) are good candidates for recovery. These landfills will generate large amounts of gas. Landfills containing large amounts of construction and demolition debris (non-organic material) will not generate adequate gas to support a recovery project. Section 3.4 discusses the waste types in more detail.

Countries with landfills which do not meet the required criteria do not have good candidates for conventional energy recovery projects.

Data collection should involve people with expertise in the landfill industry and should focus on urban and peri-urban regions.

To assist in this preliminary assessment of project opportunities, people with expertise in the landfill industry should be contacted. Information on waste type and destination could be obtained from Sanitation Departments or Waste Management Bureaus. If energy recovery projects have been implemented in the country, information on such projects would help determine the viability of recovery projects as well as provide useful sources of information for future projects. People to involve include, among others, the following:

- **Sanitation Departments.** The departments responsible for the collection and disposal of wastes would be able to provide waste related information. At a minimum, information on waste type and site of disposal could be gathered from them. This information would determine whether landfills currently accept municipal solid waste (MSW) or not.[5] Another related source of information are the Waste Management Boards, if any. Sanitation Departments and Waste Management Boards are typically found at both the national and local levels. Urban areas should be targeted as landfills are found primarily in urban areas of developing countries.

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5 Municipal solid waste (MSW) includes wastes such as durable goods, nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic wastes from residential, commercial, institutional, and industrial sources. MSW does not include wastes from other sources, such as construction and demolition wastes, automobile bodies, municipal sludges, and combustion ash.

- **Previous Energy Recovery Projects.** Energy recovery projects previously implemented are an obvious source of information. Information on such projects would assist in developing a general idea of gas recovery; the technical, economic and problematic aspects of previous recovery projects would help focus the analysis for future projects.

- **Other Leads.** Other sources of information include, but are not limited to, the Energy Ministry, Environment Ministry, and Electric Utility Board or Commission. Energy Ministries are responsible for energy supply issues, and therefore may be aware of landfill gas as a source of energy.

Each of the steps in the assessment is presented in turn. This section concludes with a summary of the overall appraisal.

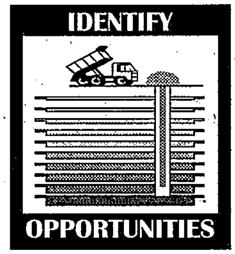
3.1 Waste Management Practices

Landfills or large open dumps with over 1 million tons of waste are likely to generate enough gas to support and economically viable gas recovery project.

The two main types of waste management practices are open dumping, which is generally practiced in rural areas of developing countries, and landfilling, generally practiced in developed countries and urban areas of developing countries. Both of these types of waste management can result in methane production if the waste contains organic matter. Gas recovery projects are appropriate for reducing methane emissions from both landfills and large open dumps. Small open dumps, common especially in rural areas of developing regions, are not suitable for gas recovery. Other waste disposal methods common in developing regions include the burning of waste for heating or cooking purposes, feeding to domestic animals, dumping in rivers or other bodies of water, or sweeping out on to the street and burying it. Landfills and large open dumps can be defined as follows:

- **Landfills.** Landfills are designed specifically to receive wastes. Their design reflects a precise engineering component, which allows for the controlled disposal of waste. Landfill design and management is becoming increasingly sophisticated in many countries, as the environmental consequences of uncontrolled dumping are better understood. New landfill design standards in many countries are ensuring that landfills are lined before receiving waste, and also that there are provisions for the safe control, and removal where appropriate, of gas and leachate generated. Good waste management practices ensure that waste is compacted to minimize the use of void space. All these factors can encourage the rapid development and maintenance of anaerobic conditions within the landfill, and result in methane production. Exhibit 3-1 presents a schematic of a typical closed landfill.

- **Large Open Dumps.** Large open dumps are sites which have been deemed appropriate for waste disposal. Wastes in open dumps generally decompose aerobically, producing no methane. However,



there is some evidence that some methane production does occur, but the amount has not been quantified. Some large open dumps will be candidates for gas recovery. Key characteristics that make large open dumps attractive for gas recovery include:

- *Geology*: The site should essentially be a "hole" in the ground. The "hole" could be a natural depression (e.g., pits or canyons) or man-made. Furthermore, the dump site should be large: at least 7 to 10 meters deep and covering an area of approximately 50 to 60 hectares.

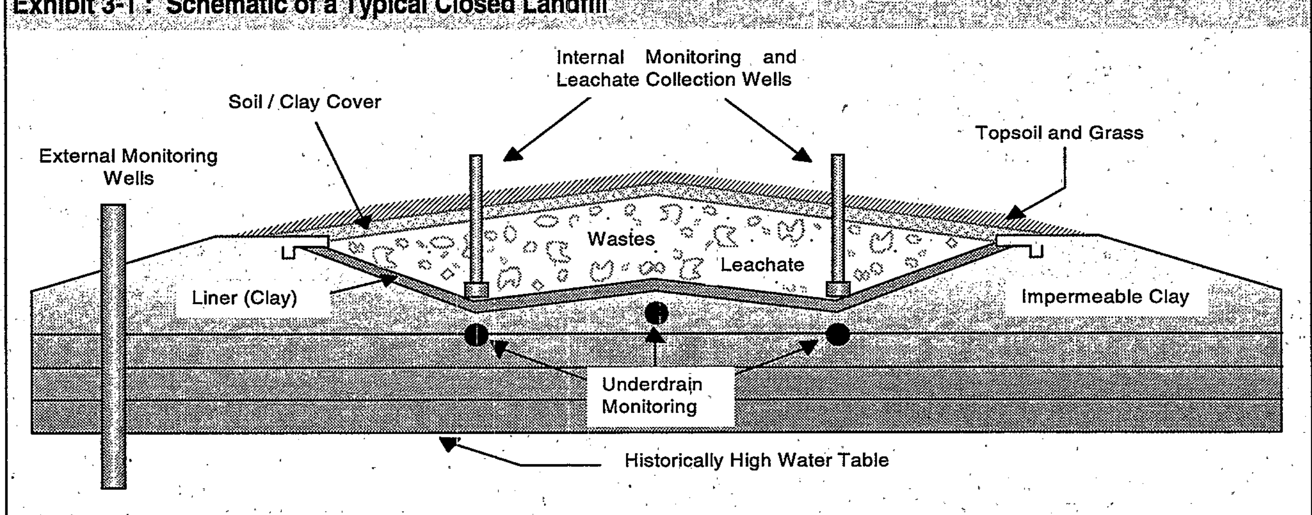
- *Waste Characteristics*: The waste should be compact and wet. Concentrated waste, usually near the bottom of an open dump, will provide the anaerobic environment necessary for gas production.

- *Liquid Control*: Good surface drainage and facilities to control leachate should be available. Additionally, the site should not be prone to flooding or "ponding."

Large open dumps that meet the above requirements would be considered candidates for recovery. Additionally, large open dumps that are being rehabilitated and upgraded to "landfill status" may also be attractive candidates for gas recovery. In particular, gas recovery can be an important aspect of efforts to upgrade the site.

As the first step, it must be assessed whether landfills or large open dumps exist in the country. The most likely place for these facilities is near large urban centers. City waste management personnel are generally most knowledgeable about whether such facilities exist and where they are located. Making contact with these individuals to identify whether landfills or large open dumps exist is an important first step in conducting this initial screening. If

Exhibit 3-1 : Schematic of a Typical Closed Landfill



such facilities exist and are found to be promising emissions reduction opportunities, these contacts will be valuable sources for information required in more detailed assessments which follow.

3.2 Use For Energy

The gas recovered from landfills can be used in nearby facilities (e.g., within 3 km) by laying pipe to connect the point of collection to the point of use, or by injecting gas into an existing gas distribution network.

The most attractive emissions reduction projects are those where the energy in the recovered gas can be used or sold. The value of the energy derived from the gas can more than offset the cost of collecting and processing the gas. The purpose of this step is to assess whether it is likely that there is a suitable use for the gas recovered from the landfill or large open dump. It should be noted that this energy use criterion is not absolutely essential. Methane emissions will also be reduced if the landfill gas is recovered and flared. However, there is unlikely to be any monetary benefit if the gas is flared. Consequently, those projects that provide useful energy are generally more attractive emissions reduction options from the cost perspective.[6]

There are three primary approaches to using the gas recovered: (1) direct use of the gas locally (either on-site or nearby); (2) generation of electricity and distribution through the power grid; and (3) injection into a gas distribution grid. Direct use of the gas locally is often the simplest and most cost-effective approach. The medium quality gas can be used in a wide variety of ways, including : residential use (cooking, hot water heating, space heating); boiler fuel for district heating; and various industrial uses requiring process heat or steam (such as in cement manufacture, glass manufacture, and stone drying).

If a direct use is not practical, the gas can be used to generate electricity by using it to fuel a reciprocating engine or turbine. If the electricity is not required on site, it can be distributed through the local power grid. This approach requires close coordination with the electric power authority.

In some cases, the gas can be injected into a gas distribution grid. If a medium quality gas system exists, the gas can be injected with minimum processing. Natural gas pipeline systems, however, typically transport high quality gas that is over 95 percent methane. Prior to injecting the recovered gas into such as system it would need to be processed extensively to remove the CO_2 and any other impurities. Processing the gas to meet high quality pipeline standards often drives the cost of production higher than the costs of alternative fuels. As a result, this option is usually not economically viable. However, in an environment of extremely high fuel costs, upgrading landfill gas might be a profitable option.

6 Even if the energy in the landfill gas cannot be put to use, reducing methane emissions from landfills and open dumps may be less costly than alternative methods for reducing greenhouse gas emissions. In particular, collecting and flaring gas is particularly inexpensive as contrasted with many other options.

Other energy utilization options may present themselves on a case-by-case basis. For example, compressed gas can be used to power refuse collection trucks that bring refuse to the landfill or open dump. Alternatively, there may be a specialized need for gas nearby, such as may be needed by a heated greenhouse. However, these are niche applications which have not been proven cost effective in developing countries.

Exhibit 3-2 presents a simple checklist to assess whether energy use options are likely to exist. Keeping in mind that this screening step is not definitive, the checklist is very general and preliminary. To complete this checklist, discussions with energy planners in the energy ministry or local power suppliers would be appropriate. If options for reducing methane emissions from these facilities appear to be attractive, the contacts made within the energy sector will be valuable for moving the project forward.

Exhibit 3-2: Are There Uses for the Energy Recovered?

1.	Are there residential areas nearby that could use a supplemental source of fuel?	Yes ❑	No ❑
2.	Are district heating plants nearby that can use medium quality gas?	Yes ❑	No ❑
3.	Are industrial facilities nearby that can use medium quality gas?	Yes ❑	No ❑
4.	Are there medium-quality gas distribution networks?	Yes ❑	No ❑
5.	Are high-quality gaseous fuels very costly, making gas processing potentially cost effective?	Yes ❑	No ❑
6.	Are there electric power distribution systems that do (or can) obtain power from projects such as landfills?	Yes ❑	No ❑
7.	Would you consider gas recovery as a lost-cost alternative approach for reducing methane emissions even if it is not profitable in its own right?	Yes ❑	No ❑

If the answer is **YES** to any of the above questions, the energy use criterion is satisfied - for initial screening purposes

3.3 "Large" Landfills and Open Dumps

The most attractive emissions reduction opportunities will be at "large" landfills and open dumps, which are defined as having over 1 million tons of waste in place. Facilities this size are expected to generate enough gas to support a profitable gas recovery project over a number of years. Additionally, a majority of the waste tonnage should be less than 10 years old.

There is no single simple approach for assessing whether any candidate landfills or open dumps have enough waste to support a recovery project. Disposal records are often incomplete or nonexistent, and can be very time consuming to review, particularly in the context of this initial assessment. Nevertheless, before proceeding to a more in-depth analysis of gas recovery options, a determination should be made that the candidate landfills and open dumps are likely to be large enough to warrant attention. Several alternative approaches are presented which may be used to make this determination.

3.3.1 Obtain Individual Landfill Information

If a number of landfills and/or large open dumps are known to exist, a structured data collection effort will help to focus on the most promising projects. This process is described further in Chapter 6.

Individual landfill information can be obtained through a survey of officials responsible for urban waste management. It is expected that most developing countries and countries with economies in transition will have a relatively small number of large landfills and open dumps, so that the survey of these officials may be relatively modest in size and scope. A telephone or written survey could be used.

To conduct the survey, the relevant officials would be asked to estimate the waste in place at the largest facilities in their areas. Some landfills, especially old ones, may not have the records required for the officials to make these estimates. Alternative approaches for estimating the waste quantity at individual landfills and open dumps are as follows:

- **Area, Depth, and Waste Density.** An estimate of the amount of waste in place can be made from the volume of the site and typical waste placement density. Data on the area and depth of a landfill can be gathered by a site visit. The density of uncompacted domestic waste as delivered to the site will be in the range of 200 to 400 kg/m^3. This will rise upon placement to approximately 600 kg/m^3 (excluding cover), or, on average, 800 kg/m^3. This may rise further on compaction and settlement to 1000 to 1200 kg/m^3.

- **Waste Records.** Landfills may have records of the amount of waste disposed. The records are usually kept on site at the gate by the gate clerks. The landfill supervisor uses this information to compile daily and monthly statistics regarding volumes, waste types, and sources. If such data is available since the year the landfill opened, the amount of waste in place could be estimated from these data. Alternatively, the person(s) responsible for monitoring or dumping waste in the landfill (e.g., gate clerks or landfill supervisors) could provide the rough estimates or recommend alternative approaches. Other, more creative ways can be adopted to determine waste volumes. For example, a landfill in Ankara (Turkey), determined the amount of waste in place using trucking records. Data on the frequency of waste disposal by trucks, obtained from the trucking records, were used along with truck capacity to estimate total waste in place at the landfill.

- **Contour Plots.** A before and after landfilling contour plot of the landfill terrain would provide an estimate of the amount of waste in the landfill. Surface topographical maps or aerial snapshots of the site are common techniques of contour mapping. The main drawback of this technique is that a before landfilling contour plot of the site is usually not available, especially for old sites.

3.3.2 Estimate Average Landfill Size

This approach relies on determining the average landfill size for a given urban area from the total amount of waste in landfills and the number of landfills in the area. It is recommended that analysis be performed for each urban area; rural areas are excluded as landfills and large open dumps are found primarily in urban areas.

The concept behind this approach is that the total amount of municipal waste generated in the urban area annually can be estimated from the total population. The portion of this waste that was placed in landfills or large open dumps is estimated, to give an assessment of the total waste in place to date. The average landfill or open dump size is estimated as the total waste divided by the number of facilities. Clearly, this is a very approximate method for screening purposes only. The steps are as follows:

<u>Step 1: Estimate Total Waste Landfilled.</u>

If this data is not readily available for urban areas, a rough assessment of waste in place can be determined using the following data: urban populations; waste generation rate per person per year; fraction of waste landfilled; and the number of years landfilling has been taking place. The amount of waste landfilled annually for an urban area is the population times the waste generated per person times the fraction of the waste that goes into landfills or large open dumps. This estimate of the annual waste landfilled (tons/yr) is multiplied by the number of years of landfilling to arrive at total waste landfilled (tons).

- **Urban Population.** It is expected that data on urban population will be readily available. The growth rate of urban populations is required to take into account changes in the population structure over the period of landfilling.

- **Waste Generation and Fraction of Landfilled Waste.** Data of waste generation per capita and portion landfilled are generally available from officials responsible for local waste management. Default estimates can be used if needed, although values can vary significantly depending on local conditions. Default values for waste generation and fraction of landfilled waste are presented in Exhibit 3-3.

Exhibit 3-3: Waste Disposal and Waste Generation Data

REGION	WASTE LANDFILLED (%)	ANNUAL WASTE GENERATION (KG/CAPITA)
Eastern Europe	85	220
Developing Countries	80	182

Source: IPCC Guidelines for Greenhouse Gas Emissions Inventories, IPCC, 1995.

- **Years of Landfilling.** To estimate total waste in place, an approximate estimate is needed of the number years during which waste has been disposed in landfills and large open dumps. In large urban areas, such practices have generally been common for at least the last 10 to 20 years. Contacts among officials responsible for local waste management will be able to provide a better figure.

Using this information, the total amount of waste placed in landfills and large open dumps is calculated as follows:

Total Waste Landfilled (tons)
=
Urban Population x Waste Generation Rate (kg/person/yr)
x Fraction of Waste in Landfills or Open Dumps x
Years of Landfilling (yr) x 0.001 ton/kg

Step 2: Determine the Number of Landfills.

An approximate number of landfills and large open dumps in each urban area is required. Again, this information is generally available from officials responsible for local waste management.

Step 3: Calculate the Average Landfill Size.

The amount of waste in landfills is determined by dividing amount of waste in landfills by the number of landfills.

Average Landfill Size (tons)
=
Total Waste Landfilled (tons) / Number of Landfills

This method will indicate whether the urban population in each city disposes of enough waste annually in landfills and open dumps to support gas recovery projects. Clearly, the assessment is crude in that is does not investigate the actual disposal histories at specific sites. Additionally, all the landfills and open dumps are assumed to share equal amounts of waste. If facility sizes vary considerably, the average size may not be a good indicator of whether gas recovery projects are likely to be attractive. Nevertheless, if the result of this rough estimate is an average waste figure greater than 1 million tons, there is likely to be at least 1 landfill which meets size the criterion.

3.3.3 Estimate the Number of People Per Landfill or Open Dump

This approach addresses the question in reverse: how many people are required to support a landfill with 1 million tons of waste. Using this estimate, urban areas with populations that are below this cutoff can be eliminated from further consideration.

Step 1: Estimate the Number of People Required Per Landfill or Large Open Dump.

The number of people required is estimated by dividing 1 million tons by: waste generation per capita per year; portion of waste placed in landfills or open dumps; and number of years of disposal in landfills and open dumps. For example, using the default values for developing counties in Exhibit 3-3 above, and assuming waste disposal for 10 years, a population of about 690,000 is required to support a single landfill.

Number of People per Landfill or Open Dump
=
Waste per Landfill or Open Dump (e.g., 1 million tons) /
[Waste Generation Rate (kg/person/yr) x Fraction of Waste in Landfills or Open Dumps x Years of Landfilling (yr)]

Step 2: Identify Candidate Cities.

Given the cutoff population estimate, those cities with populations above the cutoff are identified from census information.

Step 3: Review Candidate Cities.

Once the candidate cities are identified, each should be reviewed to obtain better city-specific information on waste generation and disposal practices. In particular, the presence of multiple landfills or large dumps should be explored to assess whether the average population per facility is large enough to support a 1 million ton site.

Based on the results of one or more of these three options, a determination is made as to whether there are landfills or open dumps large enough to warrant further analysis.

3.4 Waste Characteristics

Waste characteristics influence both the amount and the extent of gas production within landfills. MSW contains significant quantities of degradable organic matter. The decomposition (fermentation) of this organic material leads to methane emissions. Different countries and regions are known to have MSW with widely differing compositions: wastes from developing countries are generally high in food and yard wastes, whereas developed countries, especially North America, have a very high paper and cardboard content in their MSW. Landfills in developing countries will tend to produce gas quickly (completing methane production within 10-15 years) because putrescible material decomposes rapidly. Landfills with a high paper and cardboard content will tend to produce methane for 20 years or more, at a lower rate.

Landfills with MSW are good candidates for gas recovery projects. If hazardous materials are mixed with the MSW, the recovered gas may contain trace quantities of hazardous chemicals which should be removed from the gas prior to utilization. Higher gas purification requirements translate to higher costs.

If landfills or large open dumps primarily have large quantities of construction and demolition debris, they will not produce as much gas as would otherwise be expected. Therefore, these sites may not be good candidates for gas recovery.

As a final step, the waste types contained in the promising facilities identified in the previous steps should be assessed. As discussed above, disposal records are often incomplete or nonexistent. Consequently, unless a special study has been undertaken for a specific city or facility, it is unlikely that good data are readily available regarding waste composition in landfills and open dumps. To undertake this initial assessment, it is recommended that officials involved with the operation of the major facilities under consideration be contacted to discuss whether degradable MSW is a significant portion of the waste landfilled and whether hazardous materials might have been disposed of at the site.

IDENTIFY OPPORTUNITIES

3.5 Initial Appraisal Results

Using the information from the above four steps, the initial appraisal can be performed. Exhibit 3-3 lists the questions addressed by the four steps. If each of the four questions listed in the exhibit can be answered "Yes," there are likely to be good opportunities for reducing methane emissions through the implementation of gas recovery projects.

Even if one or more questions cannot be answered "Yes," there may be attractive opportunities for reducing emissions under certain circumstances. The following conditions would favor gas recovery from landfills:

- **Energy Shortage.** In areas of acute energy shortage, a gas recovery project may be highly desirable as a source of provides energy for the local area. In such cases, the profitability of a gas recovery project is better evaluated in terms of the value of energy recovery per household (e.g., $3[7] per household served by the energy recovery project) rather than a cost-revenue comparison.

- **High Energy Cost.** A high cost of alternative fuels, especially natural gas, would favor gas recovery projects. In such high cost environments, smaller sites (e.g., 500,000 to 1 million tons of waste) would potentially support profitable gas recovery projects.

- **Marginal Upgrading Cost.** Some facilities may already have gas collection systems in place to prevent off-site gas migration. These collection systems may be required to ensure the safe operation of the facility. At these facilities, the marginal cost of installing a utilization system might be small. In some cases, the collection system might require upgrading to maximize recovery of gas generated. Even small landfills would be potential candidates for gas recovery in such cases.

The initial appraisal screening criteria determine whether there are landfills or large open dumps that have the characteristics that generally support economically viable gas recovery projects.

Finally, as discussed above, it may be desirable to recover and combust methane from landfills and open dumps even if they do not meet the criteria listed above. In particular, even if there is no opportunity to use the gas for energy, methane emissions can be reduced at relatively low cost by simply collecting and flaring the gas. Such projects may be attractive to investors in developed countries who are identifying low-cost options for reducing greenhouse gas emissions through joint international action.

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[7] Currency units are in U.S. dollars. This applies throughout the document.

Exhibit 3-3: Initial Appraisal Results Checklist

1.	Are there landfills or large open dumps (currently receiving waste or closed recently) that could be potential candidates?	Yes ❑ No ❑
2.	At the potential candidate sites, are there potential uses for the energy recovered?	Yes ❑ No ❑
3.	Do the candidate sites have at least 1 million tons of waste in place?	Yes ❑ No ❑
4.	Do the candidate sites contain primarily Municipal Solid Waste?	Yes ❑ No ❑

If the answer is **YES** to all of the above questions, there are promising options for gas recovery. Proceed to Chapter 4, where the technical and economic feasibility of gas recovery at each candidate site will be evaluated.

4. PRELIMINARY SITE ASSESSMENTS

THIS section presents guidance for conducting preliminary assessments of the candidate sites identified in Section 3 in order to provide a more complete and concrete assessment of the attractiveness of each of the gas recovery opportunities. Site specific information will be collected to identify the project development options that are most technically appropriate and cost effective.

Some countries may not have the technical and labor resources needed to conduct site assessments. Appendix A (at the end of this chapter) lists landfill developers that may be contacted to conduct project feasibility assessments and develop gas recovery projects. Furthermore, Chapter 6 presents steps for identifying and filling gaps in the availability of technology and expertise required.

In most cases, the screening process in Section 3 will identify several candidate sites worthy of this level of analysis. Under this circumstance, a preliminary site assessment can be conducted for each site. However, in some cases many sites may be considered candidates, and it may not be possible to conduct preliminary site assessments for each at this time. In this case, it is recommended that several <u>representative</u> sites be selected for assessment. For example, one site in each major city could be selected. Alternatively, several sites that represent a range of sizes and locations could be selected. Based on the results of the analysis of the representative sites, the need for additional preliminary assessments can be examined.

This section presents a pre-feasibility site assessment aimed at evaluating the technical and economic feasibility of gas recovery. This is a preliminary assessment, designed to allow countries to get sufficient data to show that there is merit in pursuing the project further.

The preliminary site assessment examines the main factors influencing the attractiveness of gas recovery projects, including the gas generation rate, the market for energy, and costs. Section 4.1 identifies the general site information required. Then, Section 4.2 addresses the technical feasibility of alternative recovery and utilization options. Finally, Section 4.3 discusses the economic feasibility of these methods.

4.1 General Site Information Required

The preliminary site assessment begins with the collection of general site information. This information will be used to examine the potential uses for the gas recovered and the quantity of gas likely to be produced, which are discussed in turn.

4.1.1 Potential Gas Usage

To assess gas use options, a general survey of energy-using opportunities around the site is conducted. Information is collected for three options:

- **Local Gas Use.** Potential gas users include residences and industries located within a radius of about 3 kilometers (km) of the site. Beyond this distance, gas transmission costs are often too high to support profitable gas recovery and use. Local use of the recovered gas is generally the simplest and often most cost effective option. Any industry in the vicinity of the landfill which is amenable to the use of an alternative fuel source, i.e., landfill gas, is a potential customer.

- **Electricity Generation.** The possibility of delivering electricity generated on site to a local power grid is examined. The power grid must be capable of handling the electricity generated and must be relatively close (within about 1 km of the site) to be cost effective.

- **Pipeline Injection.** The possibility of injecting the gas into a pipeline grid carrying medium or high quality gas is examined. The pipeline grid must be within a radius of about 3 km in order to be cost effective.

Special institutional relationships may need to be developed to create markets for energy derived from landfill gas. As a result, significant government involvement may be required to facilitate landfill gas recovery projects in developing countries.

To collect the necessary information, visits to the site and its surrounding area are required to identify potential energy users. Once the potential energy users are identified, information is required about each in order to assess whether their energy needs can be met by the landfill gas produced at the site. Exhibit 4-1 presents the information required to assess potential gas usage.

Using this information, an overview of the total nearby energy demand is developed. Additionally, the potential ability to supply energy to wider distributions systems (electric and gas) are identified. This potential demand will be compared below to the energy that potentially can be produced at the site.

It is expected that not all the above information will be available from all the relevant facilities. As much information should be obtained as possible within the time and resources available so that a reasonable overview of the energy situation can be obtained. If necessary, "general usage factors" regarding energy requirements for individual industries or residential use can be applied to provide a rough approximation of the likely energy demand.

4.1.2 Potential Gas Production

Before a gas recovery project can be considered at a landfill site, an estimate is needed of the current and potential future amount of gas that can be produced. The amount of gas that can be collected depends on several factors, including, among others, the amount of waste in place, waste characteristics, and facility and collection system designs.

Exhibit 4-1: Assessing Potential Gas Usage

Step 1. Identify Potential Energy Users

1.1 Are there any significant on-site energy needs (e.g., heating or electricity loads)?

1.2 List any Industrial facilities within 3 km of the site which have significant energy needs.

1.3 List any commercial or residential facilities within 3 km of the site that have significant energy needs.

1.4 Identify the closest electricity transmission line.

1.5 Identify the closest gas pipelines and gas type (medium or high-quality).

Step 2. Identify Energy Requirements

2.1 For each on-site use or nearby facility (industrial, commercial, residential), collect or estimate the following information:

- Total energy consumed in the past year by type: electricity; gas/oil/coal.
- If energy consumption varies by season, average and peak daily energy usage by season and by type.
- Describe any special energy requirements, e.g., gas quality for specialized equipment or peak electric power requirements for specialized equipment.
- Describe any expected trends in energy requirements.

2.2 For electricity transmission lines, identify the capacity of the line and whether it operates at full capacity. Identify whether additional electric power generation capacity is planned for the grid.

2.3 For gas pipelines, identify the quality characteristics of the gas carried. Identify the capacity of the line and whether it operates at full capacity. Identify whether additional gas supply is planned for the grid, at least seasonally if applicable.

Three approaches for estimating current and potential future gas production are available.[8] The most reliable approach for estimating current gas production is to drill test wells into the waste. This approach is described first. Because it can be costly to implement, this approach should not be taken until initial assessments indicate that there is a relatively high likelihood that there are uses for the gas and that there is enough waste to produce a reasonable amount of gas. Consequently, estimation procedures are used initially.

Estimating the gas production potential is critical in determining the technical specifications of the project and assessing its economic feasibility.

8 Most countries will be familiar with the IPCC method of estimating landfill methane emissions which is used in compiling national inventories of greenhouse gases as required by the UNFCCC. Since the IPCC method is a top-down approach, it is more appropriate for a national assessment than a site-specific analysis. The approaches presented in this chapter are appropiate for site-specific assessments.

There are three estimation procedures that can be used. To conduct a preliminary assessment, a rough approximation method is presented that does not require specific information regarding waste characteristics. More detailed modeling approaches are presented that can be tailored to site-specific conditions. Each of these methods is described in turn.

Method 1: Test Wells.

The most reliable method for estimating gas quantity, short of installing a full collection system, is to drill test wells and measure the gas collected from these wells. To be effective, the wells must be placed in representative locations within the site. Individual tests are performed at each well to measure gas flow and gas quality. The number of wells required to predict landfill gas quantity will depend on factors such as landfill size and waste homogeneity.

A general rule applied by landfill developers in developing countries and countries with economies in transition to estimate the rate at which a sustainable gas yield can be drawn from a site using test wells is to cut in half the amount of gas collected by test wells (Jansen, 1995). This is done because wastes at these sites are often loosely compacted or spread in varying amounts across the landfill. Also, gas migration at these sites is a common problem which can bias gas collection figures upward. Furthermore, cutting the test estimates in half provides a conservative estimate of gas production, which is important for purposes of determining the size of the energy recovery system. Later, if it is determined that the gas is being under-utilized, it is easy to supplement the collection system; however, the reverse is not true.

There are a variety of methods for estimating gas production - ranging from basic desktop estimates to actual field tests. As both the cost and reliability of the estimates increase for more detailed methods, it is recommended that basic estimation approaches be used first, and more detailed methods be used (if warranted) as project assessment progresses.

An added benefit of this method is that the collected gas can be tested for quality as well as quantity. The gas should be analyzed for methane content as well as hydrocarbon, sulfur, particulate, and nitrogen content. This will help in designing the processing and energy recovery system.

Method 2: Rough Approximation.

The simplest method of estimating the gas yield from a landfill site is to assume that each ton of waste will produce 6 m^3 of landfill gas per year. The procedure for approximating gas production is derived from the ratio of waste quantity to gas flow observed in the many diverse projects already in operation. It reflects the *average* landfill that is supporting an energy recovery project, and may not accurately reflect the waste, climate, and other characteristics present at a specific landfill.

This rough approximation method only requires knowledge of how much waste is in place at the target landfill or large open dump. The waste tonnage should ideally be less than 10 years old. Estimates from this approximation should be bracketed by a range of plus or minus 50%. This rate of production can be sustained for 5 to 15 years, depending on the site.

SITE ASSESSMENT

Method 3: Model Estimates

Although test wells provide real data on the site's gas production rate at a particular time, models of gas production predict gas generation during the site filling period and after closure. These models typically require the period of landfilling, the amount of waste in place, and the types of waste in place as the minimum data. Two main models used for emissions estimating purposes are the "First Order Decay Model" and the "Waste In Place Model."

The First Order Decay Model accounts for the fact that methane is emitted over a long period of time rather than instantaneously. As such, it can be used to project future gas production.

The "First Order Decay Model" accounts for changing gas generation rates over the life of the landfill. The model, therefore, takes into account the various factors which influence the rate and extent of gas generation. The model requires that the following five variable be known or estimated:

- the average annual waste acceptance rate;
- the number of years the landfill has been open;
- the number of years the landfill has been closed, if applicable;
- the potential of the waste to generate methane; and
- the rate of methane generation from the waste.

The basic first order decay model is as follows:

$$LFG = 2 L_0 R (e^{+kc} - e^{-kt})$$

where:

LFG	=	Total amount of landfill gas generated in current year (m^3/yr)
L_0	=	Total methane generation potential of the waste (m^3/kg)
R	=	Average annual waste acceptance rate during active life (kg)
k	=	Decay constant for the rate of methane generation (1/year)
t	=	Time since landfill opened (years)
c	=	Time since landfill closure (years)

The methane generation potential, L_0, represents the total amount of methane that one kilogram of waste is expected to generate over its lifetime. The decay constant, k, represents the rate at which the methane will be released from each kilogram of waste. If these terms were known with certainty, the first order decay model would predict landfill gas generation relatively accurately; however, the values for L_0 and k are vary widely, and are difficult to estimate accurately for a particular landfill.

Ranges for L_0 and k values developed by an industry expert are presented in Exhibit 4-2. Since these values are dependent in part on local climatic conditions and waste composition, it is recommended that others in the local area with similar landfills who have installed gas collection systems be consulted to narrow the range of potential values. Note that for different climatic conditions, the L_0 (total amount of landfill gas generated) remains the same, but the k value (rate of landfill gas generation) changes, with dry climates generating gas more slowly. Because of the uncertainty in estimating k and L_0, gas flow estimates derived from the first order decay model should also be bracketed by a range of plus or minus 50 percent.

Exhibit 4-2: Suggested Values for First Order Decay Model Variables

VARIABLES	RANGE	SUGGESTED VALUES		
		Wet Climate	Medium Moisture Climate	Dry Climate
L_0 (m^3 CH_4/kg)	0 - 0.312	0.14 - 0.18	0.14 - 0.18	0.14 - 0.18
K (1/yr)	0.003 - 0.4	0.10 - 0.35	0.05 - 0.15	0.02 - 0.10

Source: Landfill Control Technologies, "Landfill Gas System Engineering Design Seminar," 1994.

The "Waste In Place Model" was developed from data on gas recovery projects in the United States (USEPA, 1993a). This model relates gas production to the quantity of waste in the facility, but does not consider the aging of the waste and the changing rate of gas production over time. This model is as follows:

$$LFG = 2\,[4.32 + 2.91W - 1.1W \cdot D]$$

where:

LFG = Total landfill gas generated in the current year (10^6 m^3)
W = Total waste in place that is less than 30 years old (10^6 tons)
D = Indicator for arid conditions (1 when precipitation < 63.5 mm/yr).

This model was specified only for large landfills with at least one million tons of waste in place. As indicated in the equation, the emissions coefficient is reduced when the landfill is located in an arid region, which is defined as having less than 63.5 mm (25 inches) of precipitation per year.

It should be noted that not all landfill gas generated in the landfill can be collected. Some of the gas generated in a landfill will escape through the cover of even the most tightly constructed and collection system. Newer systems may be more efficient than the average system in operation today. A reasonable assumption for a new collection system that will be operated for energy recovery is 70 - 85% collection efficiency. The estimates from the First Order Decay Model and the Waste In Place Model should be multiplied by this range of collection efficiencies (70 - 85%) to determine the potential collectable gas from the site.

Exhibit 4-3 compares estimates of gas recovery for the three estimating methods. As shown in the exhibit, the Rough Approximation method produces the lowest estimates of gas recovery. As such, it will be the most conservative estimate for purposes of conducting the site assessment. The First Order Decay Model produces the highest estimates, but its estimates are very sensitive to the assumptions made about the timing of the waste disposal and gas recovery. The First Order Decay and Waste In Place estimates shown in the exhibit incorporate a 75 percent collection efficiency.

Exhibit 4-3: Landfill Gas Production: A Comparison of Methods

LANDFILL SIZE (million tons of waste)	LANDFILL GAS RECOVERED† (million m³ per year)		
	Rough Approximation	First Order Decay Model*	Waste In Place Model
1.0	6	7 - 11	9 - 11
1.5	9	10 - 16	11 - 13
2.0	12	14 - 21	12 - 15
3.0	18	21 - 32	15 - 20

† Landfill Gas Recovered estimates incorporate a 75% collection efficiency for the First Order Decay and Waste in Place Models.

* The estimates for the First Order Decay Model are 10-year averages. The lower value is for the 10 years following closure of a landfill that was open for 20 years. The higher value is for the 10 years following closure of a landfill that was open for 10 years. Waste acceptance is assumed to be constant during the open period. All estimates use the mid-point values for L_0 and k for Medium Moisture Climate.

4.1.3 Comparing Gas Flow Estimates to Potential Energy Uses

At this point in the assessment it is instructive to compare the gas flow estimates to the potential energy uses described above. Keeping in mind that the landfill gas estimates are assumed to be about 50 percent methane, the potential annual energy produced at the landfill can be compared to the potential energy uses. If the energy production appears to be much larger than the likely uses for the energy, additional investigation into potential uses is warranted prior to continuing with the analysis. If it becomes clear that more energy can be produced than can be used or distributed to others, then flaring of the gas may need to be considered as a means for reducing emissions. Alternatively, if there are several potential uses for the energy which equal or exceed the likely energy production, then the site assessment should continue with the assessment of technical options described in the next section.

Remember that landfill gas is typically only about 50 percent methane.

4.2 Gas Recovery and Utilization Technologies

This section presents the technologies used to recover and utilize gas from landfills and open dumps. Gas recovery options are relatively limited and straightforward. The landfill characteristics required to support recovery are discussed. Then, the primary technologies for making productive use of the recovered gas are presented.

Profiles of Gas Recovery at Two Very Different Landfills:

Puente Hills Landfill

The Puente Hills landfill in California, USA receives 12,500 tons of waste per day, and collects about 1 million cubic meters of gas per day. The gas is used in three ways:

- *to generate approximately 50MW of power;*
- *as a vehicular fuel; and*
- *as a fuel for a boiler.*

Puente Hills is the largest landfill gas recovery project in the U.S.

The Battleboro Landfill

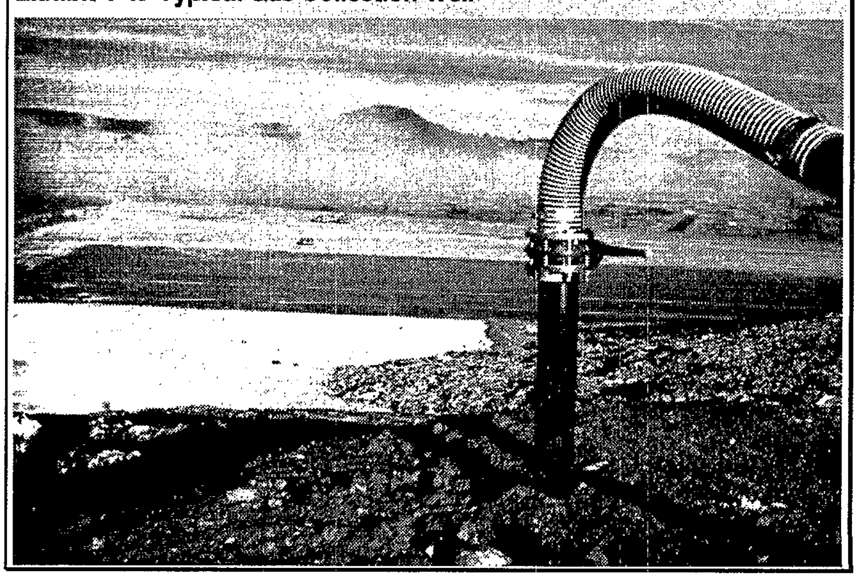
The Battleboro Landfill in Vermont, USA, is one of the oldest landfill gas recovery projects in the country. When energy recovery began in 1983, the landfill contained less than 1 million tons of waste. The approximately 11,000 cubic meters of gas collected per day in the landfill is used in IC engines to generate less than 1 MW of electricity, which is sold to the local utility.

4.2.1 Gas Recovery Technologies

To recover gas from a landfill or large open dump, vertical or horizontal wells are drilled into the waste where methane is being produced. The wells are connected by horizontal piping to a central point where a blower removes gas under negative pressure. Recovery systems are usually operated as part of an overall gas control system. A typical gas recovery system generally includes a backup flare. This section provides a brief overview of each component, and outlines the major characteristics of energy recovery systems that determine their applicability at a given site.

The best source of the information to perform a technical assessment of recovery methods will be individual facility operators. Operators can provide detailed information regarding recovery methods currently used, waste characteristics, and geological and other site characteristics. The above data can be collected in several ways. For example, officials can be sent to the landfills to obtain the required information, a conference could be held with landfill operators, a survey could be mailed to operators, or operators could simply be contacted by phone.

Exhibit 4-4: Typical Gas Collection Well



SITE ASSESSMENT

Typical landfill gas collection systems have three main components: collection wells; a blower (compressor); and a flare for use when gas production exceed gas use. Each of these components is described below.

Gas Collection Wells

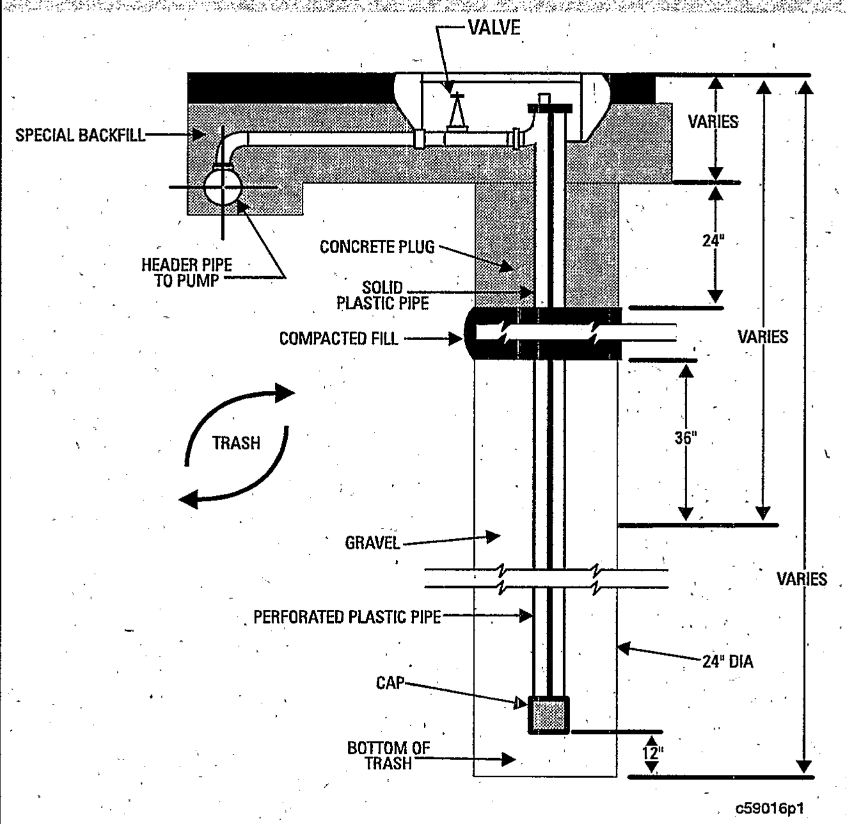
Gas collection typically begins after a portion of a facility (e.g., a landfill cell) is closed. There are two collection system configurations: vertical wells and horizontal wells. Vertical wells, shown in Exhibit 4-4 and 4-5, are by far the most common type of well used for gas collection. Horizontal wells may be appropriate for landfills which need to recover gas promptly (e.g., landfills with gas migration problems). Regardless of whether vertical or horizontal wells are used, each wellhead is connected to lateral piping, which transports the gas to a main collection header (USEPA 1995). Ideally, the collection system should be designed so that the operator can monitor and adjust the gas flow if necessary.

U.S. landfill developers estimate that one gas collection well is required for every 0.4 hectares (1 acre) of landfill.

Blower

A blower (or compressor) provides the negative pressure to pull the gas from the collection wells into the collection header. The size, type, and number of

Exhibit 4-5: Schematic of a Typical Gas Collection Well



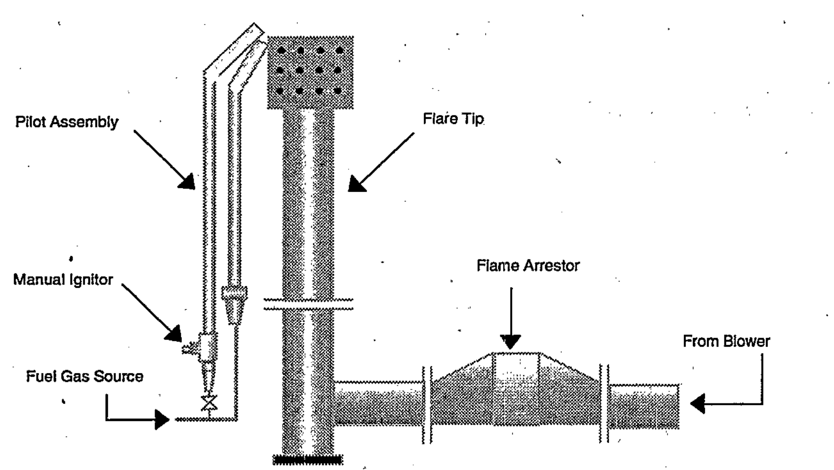
blowers needed to withdraw the gas from the landfill or open dump depends on the gas flow rate. Additional gas compression may be required depending on how the gas is used. However, the amount of compression required solely for withdrawing the gas from the facility is generally quite small because only a slight negative pressure is required. For example, a facility with 2 million tons of waste may produce about 15 million m3 of gas per year, or about 28.5 m3 per minute. Given that about 0.3 to 0.8 horsepower (hp) is required per m^3/min of gas flow, total blower hp requirements are only about 36 to 95 hp.

Flare

A flare burns the recovered gas when it cannot be used. The gas will readily form a combustible mixture with air, and requires only an ignition source to ensure combustion. The flame can burn openly or can be enclosed.

- **Open Flame Flares.** Open flame flares (e.g., candle or pipe flares) are the simplest flaring technology. They consist of a pipe through which the gas is pumped, a pilot light to spark the gas, and some means of regulating the gas flow. Possible complications include unstable flames leading to inefficient combustion, aesthetic complaints, and the difficulty of testing emissions from open flames. Some open flame flares are covered, both hiding the flame from view and allowing relatively accurate monitoring for low flow rates. Exhibit 4-6 presents a diagram of a typical open flare.
- **Enclosed Flares.** Enclosed flares are designed to overcome the problems associated with open flame flares. Because the air flow can be adjusted, the combustion is more reliable and more efficient. As a result, unburned hydrocarbon and hazardous material emissions are reduced. However, these flares cost several times more than the open flame flares.

Exhibit 4-6: Typical Open Flare



Most energy recovery systems will have flares to remove excess gas whenever required (e.g., during system startup and downtime, system upgrades, etc.). Flaring may also be considered as the principal emissions control strategy for situations in which gas utilization is not appropriate.

These three components must be used to recover the gas. In order for gas recovery to be technically feasible, the facility must be able to sustain the drilling of wells. The waste into which the wells are drilled must be relatively stable, and cannot be saturated with water. Some facilities have impermeable barriers below (such as clay liners) which trap water. If this water is not removed via a leachate collection system, the waste can be cone saturated and unable to sustain gas recovery wells. Test wells can be used to verify that the waste can support gas recovery wells.

4.2.2 Gas Utilization Technologies

As discussed above, methane recovered from landfills and large open dumps can be used in a variety of applications. The selection of which option to use depends first on the requirements for energy on-site and in the surrounding area. Once these needs are identified, the most attractive options will be those that are compatible with the quantity and quality of gas that can be produced at the facility.

This section describes the main gas utilization technologies. Based on the energy use information collected above, several candidate utilization options should be identified. The preferred option can then be determined based on costs or other considerations. Exhibit 4-8 summarizes the main options.

Landfill gas-to-energy projects involve technologies that are generally well developed and commercially available in most countries.

Local Gas Use

The simplest option for using the recovered gas is local gas use. This option requires that the gas be transported, typically by a dedicated pipeline, from the point of collection to the point(s) of gas use. If possible, a single point of use is preferred so that pipeline construction and operation costs can be minimized.

Prior to transporting the gas to the user, the gas must be cleaned to some extent. Condensate and particulates are removed through a series of filters and/or driers. Following this minimal level of gas cleaning, gas quality of 35 to 50 percent methane is typically produced. This level of methane concentration is generally acceptable for use in a wide variety of equipment, including boilers and engines. Although the gas use equipment is usually designed to handle natural gas that is nearly 100 percent methane, the equipment can usually be adjusted easily to handle the gas with the lower methane content.

To assess the feasibility of this option, countries need to estimate the length of the pipeline needed to transport the gas to the potential user. As discussed above, distances over about 3 km are typically not cost effective. Additionally, there must be a path along which the pipeline can be constructed. Barriers such as rivers or excessively hilly terrain can make pipeline installation prohibitively costly. For each potential local use option, estimate the pipeline length required by visiting the site and driving or walking the path that the pipeline could follow. Alternatively, local maps could be used to estimate these items.

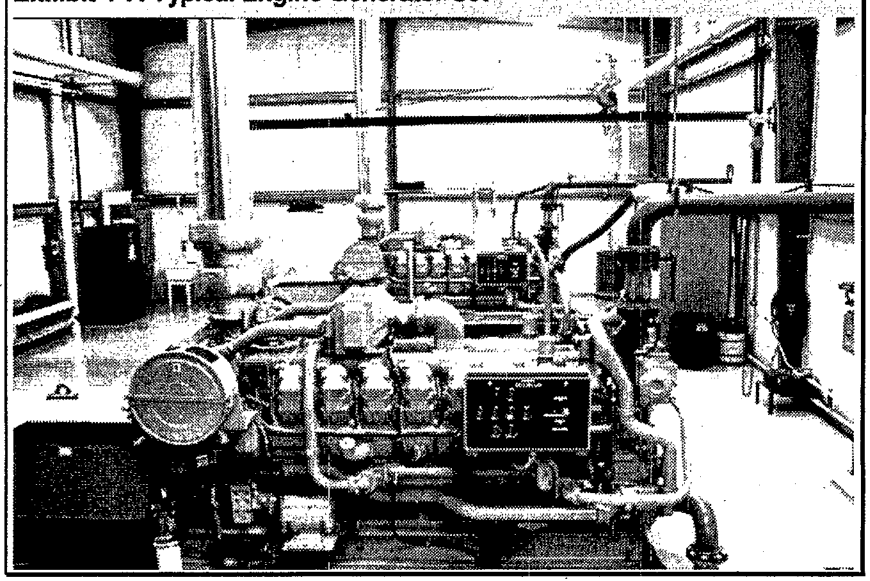
Electricity Generation

Electricity can be generated for on-site use or for distribution through the local electric power grid. There are several available technologies for generating electricity: internal combustion engines (ICs) and gas turbines are the most commonly used prime movers for landfill gas energy recovery projects.

The anticipated landfill gas flow rate is particularly important in choosing an appropriate prime mover to generate electricity. Gas turbines typically require higher gas flows than IC engines to make them economically attractive. Therefore, gas turbines are generally suitable only for large landfills. Additionally, gas turbines are expected to run relatively constantly, and as a consequence are not turned on and off to match changing electricity loads during the day. Consequently, gas turbines are commonly used to generate electricity that will be distributed through the electric power grid on a continuous basis. IC engines can more easily be turned on and off, and are therefore suitable for supplying intermittent on-site power needs as well as distribution through the grid.

- **Internal Combustion Engines.** Internal combustion engines are the most commonly used conversion technology in landfill gas applications. They are stationary engines, similar to conventional automobile

Exhibit 4-7: Typical Engine Generator Set



engines, that can use medium quality gas to generate electricity. While they can range from 30 to 2000 kilowatts (kW), IC engines associated with landfills typically have capacities of several hundred kW.

IC engines are a proven and cost-effective technology. Their flexibility, especially for small generating capacities, makes them the only electricity generating option for smaller landfills. At the start of a recovery project, a number of IC engines may be employed; they may then be phased out or moved to alternative utilization sites, as gas production drops.

IC engines have proven to be reliable and effective generating devices. However, the use of landfill gas in IC engines can cause corrosion due to the impurities in landfill gas. Impurities may include chlorinated hydrocarbons that can react chemically under the extreme heat and pressure of an IC engine. In addition, IC engines are relatively inflexible with regard to the air:fuel ratio, which fluctuates with landfill gas quality. Some IC engines also produce significant NO_x emissions, although designs exist to reduce NO_x emissions.

- **Gas Turbines.** Gas turbines can use medium quality gas to generate power for sale to nearby users or electricity supply companies, or for on-site use. Gas turbines typically require higher gas flows than IC engines in order to be economically attractive, and have therefore been used at larger landfills; they are available in sizes from 500 kW to 10 MW, but are most useful for landfills when they are 2 to 4 MW (USEPA, 1993c). Also, gas turbines have significant parasitic loads: when idle (not producing power), gas turbines consume approximately the same amount of fuel as when generating power. Additionally, the gas must be compressed prior to use in the turbine.

In addition to these two main options, there several additional options for producing electricity. Fuel cells, an emerging technology, are being tested with landfill gas. These units, expected to be produced in the 1 to 2 MW capacity range, are highly efficient with relatively low NO_x emissions. They operate by converting chemical energy into usable electric and heat energy. Additionally, in cases where extremely large gas flows are available, steam turbines can be used. The steam is utilized in a heat recovery steam generator, which uses the steam to turn a turbine which supplies mechanical energy to a generator.

To assess the feasibility of electricity generation countries need to know how much electricity could be used on-site or delivered to the power grid. The energy should be estimated in terms of kilowatt hours (kWh), and the capacity of the power grid to accept the electricity should be assessed. Additionally, if electricity is to be delivered to the power grid, the distance over which power lines must be installed must be estimated. As with pipeline construction, the shorter the distance the better, and geographic obstacles can cause significant increases in costs.

Pipeline injection

Pipeline injection may be a suitable option if no local gas user is available. If a pipeline carrying medium quality gas is nearby, only minimal gas processing may be needed to prepare the gas for injection. Pipeline injection requires that the gas be compressed to the pipeline pressure.

- **Medium Quality Gas.** Medium quality gas will typically have an energy value that is the equivalent to landfill gas with a 50 percent methane concentration. Prior to injection, the gas must be processed so that it is dry and free of corrosive impurities. The extent of gas compression and the distance required to reach the pipeline are the main factors affecting the attractiveness of this option.

- **High Quality Gas.** For high-quality gas, most of the carbon dioxide and trace impurities must be removed from the recovered gas. This is a more difficult and hence more expensive process than removing other contaminants. Technologies for enriching the gas include pressure swing adsorption with carbon molecular sieves, amine scrubbing, and membranes.

Enrichment of landfill gas to high quality gas depends on processes that are commercially available but currently uneconomic or impractical for use in many landfill applications.

To assess the feasibility of pipeline injection, you need to determine the locations of the pipelines and their gas quality specifications. As with the other options, the closer the pipeline the better. Additionally, the availability of capacity in the pipeline to carry the additional gas being produced must also be assessed.

Exhibit 4-8: Summary of Technical Feasibility of Utilization Options for Landfill Gas

Utilization Option	Minimum Amount of Waste in Place†	Gas Quality (Minimum CH_4 Concentration)*	Applicability
Local Gas Use			
Direct use on-site or off-site (nearby) in industrial, residential, or commercial facilities	1 million tons	35%	Off-site use facility should be within 3 km of the site. On-site usage is suitable for sites with large energy requirements, especially those that already use natural gas.
Electricity Generation			
IC (Reciprocating) Engines	1.5 million tons	40%	Electricity grid required; electricity sold must be compatible with user's equipment. On-site usage suitable for sites with auxiliary equipment requiring electricity.
Gas Turbines	2 million tons	40%	Electricity grid required; electricity sold must be compatible with user's equipment. On-site usage suitable for sites with auxiliary equipment requiring electricity.
Pipeline Injection			
Medium Quality Gas Pipelines	1 million tons	30 to 50%	A medium-quality gas pipeline network must be accessible and must have the capacity to carry the gas.
High Quality Gas Pipelines	1 million tons	95%	Extensive gas processing is required and a high quality gas pipeline network must be accessible and must have the capacity to carry the gas.
Other Options			
Flaring	Applicable for all landfill sizes	20%	Applicable at landfills of all sizes.

† Amount of waste in place should ideally be less than 10 years old. If the waste is freshly placed, options can be favorable for waste tonnage greater than 500,000 tons.

* *Source:* DTI (1993)

4.3 Economic Feasibility

The purpose of evaluating the economic feasibility of the project options is to ensure that the project meets a target level of cost-effectiveness. There may be several goals of a gas recovery project: profitability, energy supply, or emissions reductions (or a combination of the three). If only profitable projects are to be considered, then revenues must exceed costs. If a net cost can be incurred to reduce methane emissions and meet other environmental goals, the threshold may be set in terms of cost per ton of emissions avoided (e.g., \$2/ton of CO_2 equivalent emissions avoided). Alternatively, if the goal of the project is to meet energy demands of the local community, the threshold may be set in terms of cost per unit of energy supplied (e.g., \$0.07/kWh). Regardless of the objective, the capital and operating costs of the project must be estimated and balanced against the estimated revenues and other benefits.

Information from all parties potentially involved in the gas recovery project should be considered at this stage of the assessment, including potential energy users, the facility owner or operator, and equipment suppliers. If energy production or prices are regulated, information from the appropriate ministries should be obtained as well to help assess potential costs and revenue impacts. First, the cost analysis is presented, followed by the benefits analysis, which includes a discussion of how to compare the costs and benefits to assess economic feasibility.

Gas recovery might be considered a necessary environmental control option. In such cases, costs associated with gas recovery would be a necessary expense, whether gas utilization is considered or not.

It should be noted that labor and equipment costs can vary significantly among countries and regions within countries. The dollar costs estimates for equipment presented in this section represent world prices. Potential additional transportation costs or tariffs are not reflected. Additionally, operating and maintenance costs include labor charges, which can vary significantly. Adjustments to local currencies and cost conditions should be attempted whenever possible.

4.3.1 Cost Analysis

Costs of recovering and using landfill gas are highly dependent on the amount of gas involved and the specific technologies used. All projects will incur costs for gas recovery and a minimum amount of gas cleaning to remove moisture and impurities. Gas utilization costs will include equipment purchase and installation (e.g., pipelines, engines, generators), as well as maintenance and operation. Site-specific costs may include the need to obtain rights-of-way for pipelines or power lines, or pollution control equipment for engines or boilers. Each of the major cost elements is discussed in turn.

Gas Recovery Costs

Gas recovery costs are driven primarily by the number of collection wells required, the area from which gas is being collected, and the amount of gas being collected. Gas recovery costs are presented for the basic components of a typical gas recovery system. These include: gas recovery equipment; flare system; and (minimum) gas cleaning equipment. Each is discussed in turn.

- **Gas Recovery Equipment.** As a rough estimate for preliminary assessment purposes, installation costs for gas recovery systems are typically about **\$12,000 to \$25,000 per hectare.** An alternative formula presented in USEPA (1993b) based on U.S. data is **\$470,000 x $W^{0.8}$**, where W is the waste in place in millions of tons. Capital costs include surveying, drilling wells, and constructing the gas collection system. Operating costs of the recovery system will vary greatly with the complexity and scope of the system. Annual operating costs are estimated to be on the order of 10 percent of the initial installation costs (USEPA, 1993c).

To complete this preliminary cost asssessment, the following basic landfill data is required: amount of waste in place, gas flow rate, and area.

- **Flare System.** Flares are considered a component of each gas recovery system. The cost of flares depends on the design and the gas flow rate. For a typical flow rate of 8 to 20 m^3 per minute (300-700 cubic feet per minute), costs range from **\$15,000 for an open-flame combustor to \$90,000 for enclosed combustors** (USEPA, 1993c). Assuming that high combustion efficiencies are desired, relatively sophisticated flares will generally be called for. The costs of such flares can be estimated as **\$65,000 + \$1,100 x LFG**, where LFG is the quantity of landfill gas recovered in m^3/min (USEPA, 1993b).

- **Gas Cleaning Equipment.** The capital costs for filters and drying equipment needed to provide the minimum gas cleaning required to remove condensate liquids and particulates are on the order of **\$2,500 per m^3/min of gas flow.** Using this estimate, the capital costs for the equipment necessary for a facility with 2 million tons of waste in place and a gas recovery of 15 million m^3 per year is on the order of \$71,000. The operating and maintenance costs of this equipment is relatively small, and can be considered to be covered by the operating and maintenance (O&M) estimates for the collection system. Costs for gas clean up rise significantly if other impurities must be removed.

Gas Utilization Costs

Gas Recovery Capital Costs = Gas Recovery Equipment Costs + Flare System Costs + Gas Cleaning Costs

Costs of the equipment needed to use the recovered gas will vary significantly with each project. If nearby existing boilers or engines will be used, costs may be minimal. If new pipelines must be constructed, or if gas enrichment is required, costs can be significant. The following information provides the general magnitude of costs that may be incurred.

- **Pipeline Costs.** Various options require that a pipeline be constructed from the gas collection point to the point of use. The pipelines (and requisite compressors) which might typically be 10 to 15 inches in diameter, and operate at 10 to 15 pounds per square inch (psi) of pressure, have construction costs on the order of **$100,000 to $200,000 per kilometer** (USEPA, 1993c). These costs depend on several related factors, including the gas flow, the pipeline diameter and material, compressor capacity, and the terrain over which the pipeline is laid.

- **Gas Utilization Equipment.** Each piece of gas utilization equipment, such as a boiler or engine, will have its own unique costs. No guidelines are available for estimating these costs for the preliminary site assessment. The most appropriate estimate for these costs will involve the cost of adjusting existing equipment to handle the type of gas recovered from the landfill.

- **Electric Power Generation.** Equipment for generating electricity includes sufficient gas purification systems, a prime mover (e.g., a gas compressor), a generator, and auxiliary equipment such as engine controls and gas monitors. Capital costs for these components vary widely depending on the gas flow, the generating capacity, the type of prime mover, as well as other factors such as gas quality and system specific criteria.

  Electricity generation using IC engines may have additional maintenance costs, due to engine wear and frequent oil changes. due to the potentially corrosive nature of landfill gas.

  Prime mover capital costs are typically a large portion of total costs. IC engines, exclusive of other cost components, are estimated to be **$350 to $500 per kW of generating capacity** (USEPA, 1993c).[9] Typical capital costs for a complete system, including the equipment necessary to connect the project to the grid, are on the order of **$1,200 per kW of generating capacity.** These costs include the prime mover (low pressure IC engines), generator equipment, site preparation and auxiliary equipment. A high-pressure IC system, which requires gas compression, costs about **$2,000 per kW** (USEPA, 1993c).

  In addition to these capital costs, the costs of installing electric power lines must be included. The distance to the power grid and local costs per km of line should be used in making the estimate. Operating costs for electric power generation can be estimated very roughly at **$0.01 to 0.025 per kWh of electricity produced**. The precise cost will depend on the cost of labor and materials, as well as the type of equipment used.

- **Pipeline Injection.** The principal costs for pipeline injection include pipeline construction costs, gas cleaning costs, and gas compression costs. The pipeline construction costs can be taken at **$100,000 to $200,000 per kilometer** as discussed above. Gas cleaning and

[9] The desired generating capacity is estimated from the amount of energy being recovered from the facility and the energy rating of the engine-generator set.

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compression costs will vary depending on the quality specifications and operating pressure of the pipeline into which the gas is being injected. To enrich the gas to about 95 percent methane, capital costs are about **\$25,000 per m^3/min of gas flow** (assuming the gas is 50 percent methane). For a 2 million ton facility at which 15 million m^3 of gas is recovered annually, capital costs for enrichment would be about \$700,000.

Compression costs will vary depending on the operating pressure of the pipeline. The horsepower (hp) requirements can be determined from standard gas system design manuals. Examples from McAllister (1988) indicate that for each m^3/min of gas flow, the following is required: 7.2 hp/(m^3-min) is required to compress the gas to 100 psi; 12.7 hp/(m^3-min) is required to compress the gas to 500 psi; and 14.9 hp/(m^3-min) is required to compress the gas to 1,000 psi. Actual requirements will vary depending on site conditions and gas characteristics. For this preliminary assessment, compression costs on the order of **\$600 per hp** can be used.

Gas Utilization Costs
=
Pipeline Costs + Gas Utilization Equipment Costs + Electric Power Generation Costs (or Pipeline Injection Costs)

Other Costs

In addition to the cost of installing and operating the gas recovery and utilization equipment, several other costs are incurred which may include:

- **System Design.** The costs of the system design and construction management may be on the order of 15 percent of the total capital cost for the project.
- **Legal.** Siting, permitting, and land use requirements must be met. Legal costs include the costs of obtaining necessary permits and licenses, and vary greatly from project to project.
- **Royalty Payments.** Under some conditions, royalties must be paid to the landfill owner/operator. Royalties can be viewed as compensation for gas rights or as a financial incentive for allowing the project to be developed. Royalties are usually estimated as a percentage of total revenue or energy produced.
- **Financing.** Financing costs include the cost for obtaining financing as well as interest payments. Like legal costs, financing costs depend on project-specific factors and therefore vary greatly from project to project.

Using the above information and locally available data, countries should develop a complete listing of expected costs for a variety of project types (e.g., electricity generation, supply of medium-BTU gas). This information can then be used to compare economic feasibility.

4.3.2 Benefits Analysis

The goals of a gas recovery project may be several - profits, emissions reductions, energy supply, safety, and odor control. The benefits of gas recovery will be evaluated in terms of these project goals. The benefits analyzed in this section include: revenues generated from the utilization of the gas; methane emissions avoided by recovery of the gas; and energy supplied by a gas recovery project.

Artificially low energy prices can render promising energy recovery projects unprofitable.

Revenues Generated

Revenue from the gas recovery project results from the sale or use of the energy produced. The value of energy produced is estimated as the amount of energy (gas or electricity) produced multiplied by its price. If the energy is used to offset energy costs (e.g., natural gas, oil, electricity) on-site, it is an indirect source of revenue. The savings that are achieved by offsetting energy purchases can be counted as a type of revenue. Additionally, tax credits or other government incentives may supplement revenues.

The rate at which landfills can sell energy will vary according to the terms negotiated with individual customers, or may be set by national or state policy. Artificially low energy prices can adversely affect the revenues from the project. Conditions that lead to artificially low energy prices include national energy policies and subsidies for fossil fuels (discussed in Section 5 below). Other important factors affecting prices include the price of competing source of energy, supply reliability, and quantity purchased.

The economic benefit of a gas recovery project will be the income from the sale of the energy produced. This can be calculated either as direct sale of energy or the saving on energy used internally.

If electricity is to be distributed through the electric power grid, the owner/operator of the grid (such as a national electricity company) will typically purchase the electricity at the point at which it enters the grid. Under such conditions, the price for the electricity could be set to be comparable to the marginal cost of generating electricity elsewhere on the overall system. In some cases, an electric power generation project is best developed jointly with the electric power authority. It is recommended that potential pricing arrangements be explored with the proper authorities as part of this assessment.

The price of gas sold to customers can be priced on an energy-unit basis that is comparable to the price of alternative fuels, such as propane, oil, natural gas or coal. The relevant fuel price to use depends on the costs that customers are paying to use other fuels. Similarly, the price of gas injected to pipelines can be priced to be similar to the price paid for comprable gas supplies. These prices must be determined locally.

Another potential source of revenue is when a portion of the energy is used to offset on-site energy needs. The savings associated with this approach are estimated as the cost of the fuel displaced by the use of the recovered gas. These values should be estimated from on-site energy consumption records.

Tax credits or other government programs can also supplement project revenues. Some government programs may offer tax credits or subsidies for producing energy from non-conventional sources, including landfills. The applicability of these incentives usually may depend on the structure of the project and the landfill owner's status. Therefore, a complete understanding of the tax laws and their application is critical to ensuring a project's ability to take full advantage of the incentives.

Once revenues are estimated, they must be compared to project costs (estimated in the previous section). This comparison requires that a time profile of the costs and revenues from the project be developed. From the information above, the capital costs and annual operating costs can be estimated. For purposes of evaluation, it can be assumed that a project's life is 10 to 20 years, and the annual operating expenses are incurred in each year. Annual revenues can be calculated using the estimated energy sales estimates over time. Because energy prices often rise over time, using current prices to estimate revenue will generally produce a conservative estimate of annual future revenues. Using these time profiles of costs and revenues, three main techniques exist for determining the economic feasibility of the project:

- **Payback Method.** The payback method involves determining the number of years it would take for a project to generate profits equal to the initial capital outlay. This method may be particularly suitable where there is a great amount of risk and uncertainty associated with a project and the emphasis is on recovering capital expenditure as quickly as possible. The main disadvantages are that this method does not consider the costs and benefits that accrue at the end of the payback period and that it does not take into account the time when costs are incurred or benefits are received. The payback method is appropriate to use when making a rough preliminary assessment of a project's economic feasibility.

- **Discounted Cash Flow Method.** The basic premise of the discounted cash flow technique is that costs or benefits occurring in the future are worth less than those occurring now. This means that annual costs and benefits cannot simply be added up over the life of the project. The costs and benefits in each year of the project are adjusted by a discount factor so that costs or benefits occurring in one year can be compared with the costs or benefits occurring in another year. The discounted costs and benefits in each year can then be aggregated to give a **Net Present Value** (see box) of future cash flows of the project. The discount rate will normally be chosen on the basis of prevailing interest rates or on the basis of the minimum desired rate of return for the project. If the net present value is positive, the appraisal shows that the project is capable of yielding this minimum rate of return.

- **Internal Rate of Return Method.** The **Internal Rate of Return** (see box) is the discount rate at which the present value of the project would be zero. This value shows the total rate of return achieved by

The Net Present Value (NPV) is the present value of a project's cash flows, including all investment costs. If the NPV is greater than 0, a project is considered to be profitable at the chosen discount rate. The net present value can be expressed as follows:

$$NPV = \sum_{t=1}^{n} \frac{ACF_t}{(1+r)^t} - IO$$

where:

ACF_t	=	annual cash flow in year t
r	=	discount rate
IO	=	initial cash outlay
n	=	life of the project

the project. This rate can be compared to return rates from alternative investment opportunities .

The Internal Rate of Return is calculated as follows:

$$0 = \sum_{t=1}^{n} \frac{ACF_t}{(1+IRR)^t} - IO$$

where:

ACF_t	=	*annual cash flow in year t*
IO	=	*initial cash outlay*
n	=	*life of the project*
IRR	=	*internal rate of return.*

Sensitivity analyses should be carried out to examine how changes in key parameters such as electricity prices can affect the economic viability of the project. These analyses can carried out before the financing arrangements for the project have been worked out and are useful in providing an initial indication of the project's viability. Further analysis can be conducted to examine the viability of different financing schemes.

Emissions Avoided

Recovery and utilization of gas from landfills and large open dumps prevent the release of methane and other volatile organic compounds (VOCs). Methane is a potent greenhouse gas; over a 100 year period, a ton of methane emitted into the atmosphere has the equivalent global warming impact of about 24.5 tons of carbon dioxide. Because landfill gas is typically 35 to 50% methane, combusting the gas prevents its emission into the atmosphere, thereby reducing greenhouse gas emissions. In addition to methane, landfill gas often contains VOCs which contribute to ground level ozone (the principal component of urban smog).

A gas recovery project may be implemented to reduce these emissions from a landfill or open dump. The economics of such a project will be evaluated in terms of the cost of emissions avoided. For example, a threshold level of cost effectiveness may be set at $50 per ton of methane emissions avoided. If the project costs less than $50 per ton of methane emissions avoided, the project is considered cost effective.

Emissions impacts are usually assessed in terms of greenhouse gas emissions avoided (as opposed to VOC emissions avoided). The emissions impact of a gas recovery project is, simply, the amount of gas recovered and combusted. If not recovered and combusted, the methane will be emitted into the atmosphere. Methane emissions, in tons per year, can be derived using data on the gas recovered (determined above), the methane concentration in the gas, and the density of methane, as follows:

Benefits of emission reduction are difficult to evaluate in monetary terms as they do not accrue directly to a project developer. However, such benefits are important to consider in the formulation of national energy policy and tax and subsidy regimes for emissions mitigation or renewable energy projects.

Annual Methane Emissions Avoided (tons/yr)
=
Annual Landfill Gas Recovered (m^3/year) x
Methane Conc. (e.g., 50%) x 678 g/m^3 x 10^{-12}(tons/g)

The methane emissions avoided could be expressed in terms of carbon dioxide emissions avoided. The methane emissions avoided, in units of tons per year, is converted to tons of carbon dioxide per year using a Global Warming

Potential of methane equal to 21.[10] The following equation expresses the relationship.

CO_2 Equivalent Emissions Avoided (tons/yr)
=
CH_4 Emissions Avoided (tons/yr) x 21 tons CO_2 Equivalent/ton CH_4

The amount of methane recovered is an overestimate of actual methane emissions reduced. In the absence of the gas recovery system, a portion of the methane produced in the landfill would be oxidized as it migrates out of the landfill. Withdrawing gas with a collection system prevents this oxidation. The extent of oxidation that will occur depends on local conditions. Because no single oxidation factor can be recommended at this time, the amount of gas collected and utilized should be used as the estimate of emissions reduced.

Finally, landfill gas-to-energy projects will often (but not always) displace energy generated from the combustion of fossil fuels. Where it is known with certainty that a specific project will displace fossil fuels, the following calculation can be made to determine the equivalent number of fossil fuel emissions that will be avoided by implementing a gas-to-energy project:

Pollutant Emissions Avioded (g/yr)
=
Electricity Potential(kWh/yr) x System Efficiency(e.g., 0.85)
x Emission Factor for Pollutant(g/kWh)

Where:
Electricity Potential is the project's electricity generation potential; System Efficiency is the operating efficiency of the electricity generating system (default = 0.85); and Emission Factor for Pollutant is the emission factor associated with the pollutant from the fuel displaced (see Exhibit 4-9 below for emission factors).

Exhibit 4-9 : Emission Factors of Pollutants for Alternative Fuels

POLLUTANT (g/kWh)	FUEL DISPLACED		
	Coal	Natural Gas	Hydro-Electricity*
SO_2	8.2	1.1	0.5
CO_2	1.6×10^6	1.0×10^6	0.1×10^6
NO_x	2.6	1.5	0.3

* With natural gas and coal as supplementary fuels.

10 The Global Warming Potential (GWP) is a measure of the relative warming impact of a gas relative to the warming impact of carbon dioxide. One gram of methane has 21 times the impact of one gram of carbon dioxide over a 100 year period.

Energy Supplied

The cost effectiveness of a gas recovery project may be evaluated in terms of the quantity of energy supplied. The cost of gas recovery would be compared with alternative energy supply options to determine the most cost-effective option. The threshold level of cost-effectiveness may be set in terms of energy supplied per unit cost. For example, energy recovery projects which supply energy at a cost of $0.07/kWh may be defined as being cost effective if the marginal cost of alternative electricity supply options is $0.07/kWh.

In some cases, energy from the gas recovery project may be provided to customers who otherwise would be using wood (e.g., for residential cooking). The economic viability of such a project can be estimated by establishing a threshold level in terms of the number of households served by the energy supplied. This would require data on average household energy consumption. For example, a cost-effective project may be one that costs less than $3 per household served. Such evaluations are prudent in areas of energy scarcity.

4.4 References

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POLICIES

5. IDENTIFICATION AND ASSESSMENT OF KEY GOVERNMENT POLICIES

THE government can play an important role in developing domestic landfill gas resources. The policies that it formulates can promote or hinder the recovery and utilization of this clean energy source. The purpose of this section is to identify the key policies that will affect the development of landfill gas recovery projects and to assess whether these policies pose barriers that must be overcome or are potential leverage points to promote project development. Although there are various policies that can encourage landfill gas recovery projects, it is not possible to recommend a general set of policies for every circumstance. Rather, policies must be tailored individually to suit each country.

Landfill gas-to-energy projects may be developed by a project developer (or team of developers) alone, or project developer(s) in partnership with an electric or gas utility. In any case, before investing in a landfill gas-to-energy project, project developers should investigate the laws and regulations in effect in a particular country regarding independent power production, rights-of-way to utility transmission lines or pipelines, and foreign participation in energy project development.

The key government policies discussed in this section include:

- *National, Energy Pricing, Subsidies, and Taxes;*
- *National Energy Supply Priorities;*
- *Environmental Goals;*
- *Financing; and*
- *Technology Development.*

The steps to review policies and regulatory structures identify and eliminate potential barriers are presented in Chapter 6.

5.1 National Energy Pricing, Subsidies, and Taxes

The primary barrier to landfill gas recovery and use in both developing and developed countries is often artificially low energy prices. Conditions governing electricity and natural gas prices, such as government energy policies and subsidies for fossil fuels, can have an important effect on the economic viability of landfill gas projects.

Energy subsidies can both help and harm landfill methane recovery and utilization projects. Artificially low energy prices can pose a barrier to gas utilization. If the prices of natural gas, oil, and coal are less than the cost of landfill gas, it will be difficult to make an economically viable case for the utilization of recovered methane. Using market prices for natural resources would allow landfill gas to compete fairly. However, if under market prices landfill gas is still uncompetitive, the government may offer tax credits or other financial incentives to encourage these projects because of their environmental benefits.

Energy taxes must also be assessed for their impact on gas recovery projects. Energy taxes based on the carbon content of fuel would give recovered methane an advantage over coal and oil. Similarly, higher taxes on imported energy would allow domestic landfill gas to be more competitive. Depending on a nation's energy goals, the tax structure may benefit one source of energy over another.

Exhibit 5-1: United States Federal Incentives for Landfill Gas Recovery

- **Internal Revenue Service (IRS) Section 29 Tax Credit:** This is a federal tax credit for producing energy from non-conventional sources, including landfills. The value of the credit depends on a number of factors, including the domestic oil price and the inflation rate. At current oil prices, the credit is approximately equivalent to $0.01 per kWh of electricity sold. This credit is due to be renewed in 1996.

- **Renewable Energy Production Incentive (REPI):** This is an incentive established by the US Department of Energy to provide incentives to renewable energy power projects owned by a state or local government or nonprofit electric cooperative. The REPI is approximately worth up to 1.5 cents per kWh produced from a renewable energy source (including landfill gas).

In the United States, federal, state, and local incentives are available for landfill gas recovery projects. The most important incentives are the Internal Revenue Service (IRS) Section 29 Tax Credit and the Department of Energy's Renewable Energy Production Incentive (REPI). These are briefly described in Exhibit 5-1.

5.2 National Energy Supply Priorities

The nation's energy supply goals will help determine the emphasis placed upon landfill gas development. There are two main national energy concerns that may effect the promotion of gas recovery: supply security and increasing domestic demand.

Many nations are concerned about relying on foreign sources of energy. The most notable example is reluctance of many nations to depend on oil and gas from unstable regions. Because the price of natural resources has a great impact on a nation's economy, and domestic sources of energy are considered to be more stable, many nations share the common goal of increasing domestic natural resources. Therefore, nations may choose to encourage landfill gas recovery and utilization to expand their domestic supply of energy.

For nations where energy demand is growing rapidly and there are shortfalls in supply, energy policy may include the development of gas recovery projects from landfills and large open dumps to help meet the nation's energy needs. For example, in many developing nations, the shortage of energy has slowed down the process of electrification of towns and villages. The use of landfill gas as a fuel to generate electricity could help to meet the goal of universal electrification. Furthermore, the use of domestically produced energy will decrease the amount of foreign exchange required to import energy. Many developing countries and those with economies in transition face a shortage of foreign exchange.

If landfill gas recovery and utilization is consistent with a nation's energy supply priorities, it may be easier to create policies to promote its development.

For example, a nation may undertake a detailed resource assessment, or make information on technologies, financing, and pertinent policies publicly available. If, however, a nation has ample quantities of domestically produced energy, it may not be interested in developing landfill gas simply for the purpose of expanding energy supplies. Rather, in such cases, environmental goals may be more important.

5.3 Environmental Goals

A nation's environmental goals will also play a large role in determining the importance given to landfill gas recovery projects. Landfill gas recovery will be encouraged in nations where environmental issues are placed highly on the national agenda. The two main issues concerning environmental policy and their impact on landfill gas recovery can be divided into a global concern and a local/national concern.

In some countries, the regulatory structures may not address issues related to gas recovery. For example, in Turkey, legislation had to be enacted to allow a local government to enter into an agreement to purchase landfill gas.

As discussed above, reducing methane emissions addresses the global concern regarding greenhouse gas emissions. In addition, both national and local environment policy may call for the use of cleaner fuels to reduce local pollution. Landfill gas can be used to displace more polluting fuels, such as coal or oil. Methane has several advantages over other fossil fuels. Emissions of SO_2, NO_x, and particulates can be reduced through the displacement of coal (and to a lesser degree oil) with landfill gas. Landfill gas combustion produces no SO_2 or particulate emissions, and lower NO_x emissions. Additionally, by combusting the gas, VOC emissions are avoided as well. For these reasons, nations may wish to pursue landfill gas energy recovery.

5.4 Financing

In order to assess the impact of government investment polices on the financing of landfill gas recovery projects, one must look at both the overall investment regime and any financial regulations specifically concerning landfill methane. When studying the overall regime, it is necessary to examine the corporate tax structure, import and export taxes and quotas, and laws concerning foreign ownership. Low limits on foreign ownership and a high corporate tax structure in comparison to other nations with potential landfill gas recovery projects may discourage foreign investors. In cases in which the equipment must be imported from abroad, high import duties will place a burden on both domestic and foreign investors.

The government also may have financial regulations dealing specifically with landfill gas. For example, low interest loans, tax credits, and subsidies for landfill gas recovery projects will ease the financial burden on the investor. As mentioned above, the use of such incentives will depend on the overall energy and environmental goals of the government.

5.5 Technology Development

Because some of the technologies associated with landfill gas recovery and utilization may not be available in many nations, the government's policy towards the development of technology is important to assess. There are various ways in which the government can encourage the development of technologies specific to landfill gas recovery projects:

- Encourage foreign participation in landfill gas recovery projects. This would allow foreign technology to be introduced without requiring domestic capital.
- Lower import duties, taxes, and restrictions on required technologies, thereby reducing the cost of a gas recovery project.
- Fund demonstration projects at domestic landfills to allow the industry to see and understand new technologies.
- Organize study tours and training trips abroad for key personnel so that they may learn from the experiences of other nations.
- Assist the local industry in financing research and development into recovery and utilization methods.
- If technology is a strong barrier to the development of landfill gas recovery projects, government policies that encourage the transfer of technology and the development of local technology can help promote these projects.

5.6 References

USEPA (U.S. Environmental Protection Agency). 1993. *Anthropogenic Methane Emissions in the United States*, Report to the Congress, prepared by the Global Change Division, Office of Air and Radiation, EPA, Washington, D.C.

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6. NEXT STEPS

THIS section outlines the next steps for evaluating and implementing landfill gas recovery projects in developing countries and countries with economies in transition. The steps encompass a range of initiatives which may be tailored to meet individual country objectives. These initiatives are divided into the following five main areas:

- **Focus on the Most Promising Projects.** This section presents next steps for focusing on the most promising landfill gas recovery projects in your country.
- **Availability of Technology and Expertise.** This section identifies approaches for assessing whether the technology and expertise required for implementing landfill gas recovery projects are available.
- **Decisionmaker Motivation.** This section presents approaches for motivating decisionmakers to undertake landfill gas recovery projects.
- **Resolution of Regulatory Issues.** This section lists regulatory issues that should be examined to assess whether existing policies hinder or further the goal of implementing landfill gas recovery projects.
- **Funding.** This section identifies possible sources of funding for these next step activities.

Exhibit 6-1 summarizes how this chapter can be used to meet various objectives. The first column lists several common objectives and the second column lists the chapter section to consult.

6.1 Focus on the Most Promising Projects

Although the site screening and preliminary assessments discussed above in chapters 3 and 4 may show that a variety of promising projects exist, the available data may be insufficient for identifying the most promising project opportunities. In particular, if there are a large number of landfills or open dumps, detailed site-specific information on all the sites may not have been collected in the screening step (chapter 3) because of the level of resources that are required. This section provides guidance for collecting additional site-specific information that will enable prefeasibility assessment activities to be focused on the most promising opportunities. This initiative is <u>only</u> required when there are a large number of potential sites that need to be evaluated.

Exhibit 6-1: How to use this Chapter	
Objective:	**Section to Consult:**
To focus on the most promising landfill gas recovery projects.	**Section 6.1 - Focus on the Most Promising Projects** summarizes steps for collecting additional data on candidate sites to better focus efforts.
To assemble the technology and expertise needed to develop landfill gas recovery projects.	**Section 6.2 - Availability of Technology and Expertise** presents steps for identifying and filling gaps in the availability of technology and expertise needed to develop landfill gas recovery projects.
To motivate decisionmakers to invest in and implement landfill gas recovery projects.	**Section 6.3 - Motivate Decisionmakers** presents options for assisting decision makers and providing incentives.
To identify and eliminate regulatory barriers.	**Section 6.4 - Resolution of Regulatory Issues** discusses those policies and regulatory structures that should be reviewed to identify potential barriers.
To obtain funding for program development or project implementation.	**Section 6.5 - Funding** presents candidate funding sources that can be consulted.

To collect this information, a specific program activity should be defined with data collection as its objective. Such an initiative was conducted in the United States to identify the most promising landfill gas recovery opportunities (see Exhibit 6-2). Section 6.5 describes funding sources that may be contacted to obtain funding for these types of activity. A sample five step program plan for collecting the necessary data is as follows:

Step 1: Define Minimum Information

The first task is to define the minimum information that is required for each landfill or open dump site. As discussed in Chapter 3, the primary factor that makes a site a promising opportunity for gas recovery and use is the presence of a large amount of organic waste under anaerobic conditions. Previous analyses indicate landfills and open dumps with at least one million tons of organic waste can potentially support a recovery project. Therefore, it is recommended that this information collection effort focus on obtaining the best possible information on two factors:

- The number of tons of organic waste currently in place at the landfill/open dump; and
- The current annual disposal rate of organic waste (in tons) and the likely time period over which this rate of disposal will continue (e.g., 50,000 tons per year for at least the next 10 years).

Exhibit 6-2: US EPA Landfill Profiles Project

The US EPA Landfill Profiles Project was developed to identify the most promising landfill gas recovery opportunities in the United States. This information is being provided to landfill owners and operators, landfill gas-to-energy project developers, electric and gas utility companies, and other potential project participants and partners. Based on data collected primarily from files held by state, regional, and local agencies responsible for facility permitting and regulation, a minimum data set was developed from which a profile is created for each landfill. These profiles are then used to identify those landfills that may offer attractive energy development opportunities.

The profile for each landfill has the following information:

- Landfill location and operating status;
- Waste quantity;
- Existing gas collection and control; and
- Contact information (i.e., landfill owner/operator).

Based on this information, the gas recovery potential and associated environmental and energy benefits from a potential project are estimated. These profiles are currently available from the US EPA for over 450 landfills in 24 states.

Additional information on energy needs surrounding the landfill/open dump may also be collected if the information is readily available.

Step 2: Define the Data Collection Method

The purpose of this second step is to define how the data will be collected. Options may include: working with local waste management officials to review waste disposal records; measuring the current waste disposal rate and waste composition by counting disposal trucks and examining their contents for a period of time; or surveying the landfills/open dumps to estimate their volumes. The techniques to be used to collect the data should be selected based on the type of information most likely to be available and the resources available for collecting the data. It may be appropriate to test several different data collection methods before settling on the recommended approach.

Step 3: Develop a Data Handling System

The purpose of this third step is to develop a system for handling the landfill data. A database program can be used to organize the data so the subsequent data analysis and evaluation is facilitated. Data handling and quality control procedures should be developed as part of this step, including checking the accuracy of both the data collection and data entry activities.

Step 4: Collect the Data

In this step the program personnel collect the data according to the method defined in step 2. The data are entered into the data system developed in step 3.

Step 5: Analysis and Recommendations

Based on the data collected, the gas recovery potential for each landfill is estimated (Chapter 4 presents equations for estimating gas recovery). The most promising project opportunities will be those that produce the most gas in areas that can use the energy. A list of the most attractive projects can be created, along with the information available on each.

Once them most promising opportunities are identified, this information can be disseminated to potential project developers to promote the projects (see section 6.3).

6.2 Availability of Technology and Expertise

Specific technical expertise is required to plan and implement landfill methane recovery and utilization projects. Additionally, access to and experience with specialized drilling and gas monitoring equipment are needed. The absence of the necessary expertise and equipment can be an important barrier to the implementation of these projects. This issue may be particularly important in developing countries and countries with economies in transition because technical and labor resources may not be available to construct and operate the projects.

Once it has been determined that promising opportunities exist, the availability of the necessary expertise and equipment should be conducted. Ideally, one or more local experts with landfill gas recovery expertise should be identified. For example, a request for qualifications can be issued to identify local or regional individuals and organizations with the necessary expertise.

In some cases a landfill gas expert may not exist because landfill gas recovery is relatively uncommon in developing countries and countries with economies in transition. In this circumstance, a program can be organized to train local personnel in the detailed aspects of landfill gas recovery and utilization. Training programs could include visits to existing projects in other countries as well as inviting experts from other countries to give seminars.

To augment local expertise, nations may wish to contact foreign companies with the expertise necessary to complete the project. Foreign involvement may take any of a variety of forms, including the build-operate-transfer (BOT) financing model. The BOT is currently being used for various infrastructure projects in developing countries and is applicable for landfill gas development projects as well. Such arrangements with foreign companies allow technology to be introduced without requiring the use of domestic capital. For countries that have no experience with landfill gas recovery, this may be an attractive short-term option. Appendix A lists selected U.S. landfill gas development experts available to provide training or participate in project development.

6.3 Motivate Decisionmakers

Because landfill gas recovery and utilization projects are relatively new in many countries, steps to motivate decisionmakers may be needed to get promising projects built. In addition to financial incentives, several targeted initiatives have proven effective for raising the awareness regarding the benefits of such projects as well as creating the nucleus of interested parties needed to create a viable landfill gas recovery industry. Three main initiatives are recommended to provide the information needed to motivate decisionmakers: outreach activities, demonstration projects, and information clearinghouses.

6.3.1 Outreach Activities

Because the concept of recovering methane from landfills may be unfamiliar, outreach activities may be required to educate and motivate the community and its leaders on the technology and benefits of landfill gas recovery. Outreach should be targeted to the following parties:

- **Landfill owners and operators**, who may not recognize the resource they have;
- **Potential users of landfill gas**, such as utilities or nearby industrial, commercial, or large residential facilities who may not recognize the opportunity to obtain low cost energy;
- **Energy planners**, who may not recognize how energy from landfill gas can contribute to meeting local energy needs; and
- **Environmental and community groups**, who may not be aware of the environmental and safety benefits of landfill gas recovery projects.

Outreach activities to educate and motivate these parties must be defined in terms of the *message* that is being delivered and the *mechanism* that is used to deliver the message. The message must include the information needed to educate and motivate each target group. The information must be presented in a way that each target group can understand, and must be delivered in a manner that ensures that each target group receives and assimilates the in-

Exhibit 6-3: The US EPA Landfill Methane Outreach Program

EPA's **Landfill Methane Outreach Program** encourages the use of landfill gas as an energy resource. EPA enlists the support of landfill owners and operators, electric utilities, state agencies, and project developers to reduce methane emissions from landfills through the development of profitable energy recovery projects.

The Landfill Methane Outreach Program contains three important components: **State Ally**, **Utility Ally**, and **Industry Ally** programs. EPA establishes separate alliances with state agencies, utilities (including investor-owned, municipal and other public power utilities, and cooperatives), and members of the landfill gas development community (including developers, engineers, equipment vendors, and others) through a **Memorandum of Understanding** (MOU). By signing the MOU, each Ally acknowledges a shared commitment to the promotion of landfill gas-to-energy recovery at solid waste landfills, recognizes that the widespread use of landfill gas as an energy resource will reduce emissions of methane and other air emissions, and commits to certain activities to enhance development of this resource. In return, EPA commits to provide landfill gas-to-energy project assistance and public recognition of Allies' participation in the Program.

formation. Because each target group is different, separate outreach strategies may be needed for each.

For example, outreach to national planners and decisionmakers may utilize existing decisionmaking processes. Alternatively, outreach to local officials responsible for landfill operations may require seminars, training sessions, or technical guidebooks to inform them of the landfill gas recovery opportunities. Options for reaching potential foreign partners may include conducting studies through international funding agencies (discussed below in section 6.5) or issuing requests for proposals for specific projects or studies. Exhibit 6-3 summarizes the outreach program currently being used in the United States to reach these various groups.

6.3.2 Demonstration Projects

Sometimes information is not enough to promote the use of a new technology. Users may want to see the technology in use. Demonstration projects are an effective tool to test and promote the effectiveness of landfill gas recovery projects, especially in developing countries and countries with economies in transition where landfill gas recovery is uncommon. By providing analysis, technical support, and funding, the government can facilitate landfill gas recovery projects to serve as examples for the industry as a whole.

In selecting projects to support and promote, several criteria should be considered, including: choice of technology, time frame for the project, type of government assistance required, and how projects will promote the government's goals. In most cases, after a specific project is selected, technical and financial analyses will be required to evaluate the technical effectiveness of the technology and its costs and benefits.

Upon completion of the demonstration project, the results of the project must be summarized, including both positive and negative aspects and recommendations for improvement. This information must be disseminated to promote the technology. The demonstration site itself can then be used for training and education purposes.

6.3.3 Information Clearinghouses

To provide owners, developers, regulators, and other stakeholders with comprehensive information concerning all aspects of landfill gas recovery technology, finance, and economic development, a central information clearinghouse could be established. Information clearinghouses provide a central location for information where current environmental, technical, financial, and business contact information is available.

The clearinghouse can function at the national level of the country and can involve professionals from leading research and development laboratories, educational institutes, industries, and other organizations. The clearinghouse can strengthen the existing infrastructure of national and regional bodies involved in the training, information dissemination and implementation of the programs in energy efficient technology. It can also facilitate training programs and interactions with local and international experts.

The clearinghouse can also assist in developing the technical capabilities of non-governmental organizations, consultants, industry associations, and any other groups engaged in the promotion of energy efficiency activities. This can be done by conducting regular training programs (both in the field and in the classroom), thereby exposing the participants to the latest tools and techniques.

At a minimum, the information clearinghouse should contain information in the following areas:

- current technologies and new research;
- environmental regulatory requirements, siting and zoning requirements (if any);
- applicable energy purchase rules (if any);
- international and domestic capital/funding sources; and
- government energy development policies.

An automated index of all materials could be made available electronically through a bulletin board, or as a "fax-back" system. A collection of hardcopy materials could also be assembled for use by anyone interested in landfill gas

Exhibit 6-4: Polish Coalbed Methane Clearinghouse

The **Polish Coalbed Methane Clearinghouse**, established in January, 1991, is part of the Polish Foundation for Energy Efficiency (FEWE). The clearinghouse promotes coalbed methane recovery through a series of activities including:

- providing consulting services to public- and private-sector clients (e.g., assisting contractors with pre-feasibility studies on directional drilling and gob gas recovery);
- developing and evaluating demonstration projects;
- hosting conferences, workshops, and technical seminars on a variety of coalbed methane topics including business, finance, technical, and environmental issues (e.g., the Silesian International Conference on Coalbed Methane Utilization, 1994); and
- publishing journals, brochures, and newsletters (e.g., the Silesian Coalbed Methane Newsletter).

recovery. An example of a typical clearinghouse is the Polish Coalbed Methane Clearinghouse, a brief summary of which is presented in Exhibit 6-4.

6.4 Review Regulatory Framework

Regulatory barriers are key obstacles facing potential landfill gas recovery projects. Landfill gas-to-energy projects must comply with local, state, and national regulatory and permitting requirements, most of which address environmental, safety, and zoning concerns. Artificially low energy prices can pose a barrier to landfill gas utilization if the prices of alternative fuels are less than the cost of landfill gas.

In many developing countries and countries with economies in transition the regulatory frameworks do not address issues related to landfill gas recovery. This is not unusual, given that landfilling itself is a relatively new waste management practice in these countries. In some cases legislation must be enacted before contracts can be signed to begin a landfill gas recovery project. For example, in Turkey, legislation had to be passed for a local government to be able to enter into an agreement for a landfill gas project. Moreover, in most developing countries and countries with economies in transition, all major power producers are or have been State-owned. Privatization of the energy supply is only recently occurring in many countries; therefore, the concept of an independent private power developer may be unfamiliar (Watts, 1995).

The following is recommended to review the regulatory framework for landfill gas recovery and utilization: identify and evaluate existing regulations; develop feasible options for removing barriers that will not compromise other regulatory objectives; and implement the necessary changes.

6.4.1 Evaluate Existing Regulations

To evaluate the existing situation, the relevant laws, rules, regulations, and policies must first be identified and summarized by conducting literature reviews and contacting appropriate regulatory and legislative experts. In addition, attention must be paid to institutional arrangements. The following steps should be undertaken:

- **Step 1: Identify Decisionmakers.** The purpose of this step is to identify the key decisionmakers involved in the approval of landfill gas projects. These decisionmakers may include local, provincial, or national regulatory bodies that are involved in waste management, land use, zoning, energy production, financing, and equipment purchasing/importing.

- **Step 2: Identify Decision Criteria.** The purpose of this step is to identify the decision criteria used by the key decisionmakers and the underlying objectives they are trying to achieve. This information would be obtained principally through contacts with the relevant agencies and institutions in the country.

- **Step 3: Identify Typical Project Development Path.** The purpose of this step is to describe the typical path that a project would take in order to be developed. A concise listing of the major steps in getting the project defined, approved, financed, and built should be developed based on discussions with the relevant institutions involved. This summary of the project development path could then be used to promote the implementation of landfill gas recovery projects.

The results of the above steps should be compiled in a concise summary report highlighting the policies and current practices affecting gas recovery and the options available to the government to reduce the barriers to landfill gas recovery and utilization. Any policies or requirements that significantly add to the cost of the project, create uncertainty in the viability of the project, or delay its implementation should be identified as major barriers requiring further analysis.

6.4.2 Develop Feasible Options

The purpose of this section is to develop available options for overcoming any major barriers identified above. The options selected will be those that most effectively promote the government's development objectives and are feasible in terms of political acceptance, effectiveness, secondary impacts, costs, and legality.

An Evaluation Team consisting of the decisionmakers and participants involved in landfill gas recovery and utilization can be established as a working group to guide this process. This group would be charged with ensuring that the recommended options incorporate the views of the representative stakeholders in each area. At a minimum, the Evaluation Team should include the following groups:

- **Regulatory Community:** municipal agencies, local government regulators, public utility commissions, environmental control agencies, and others;
- **Owner, Operator, and Developer Community:** landfill owners, operators, recognized local, national, or international landfill gas recovery project developers; and
- **Financial Community:** local, national, or international grant/loan agencies and venture capitalists.

The assessment of available options will involve considerable debate on which options can be implemented without compromising other pressing national priorities. As such, proposed regulatory changes must be viewed in the context of their impact on other national priorities.

6.4.3 Implement Options

Using the input and recommendations of the Evaluation Team, the options or optimum mix of options can be implemented. The implementation strategy will depend on the type of option to be implemented. Implementation strategy options include, among others:

- legislative/regulatory actions (environmental, safety, zoning, import restrictions);
- administrative and executive actions (committees, meetings, conferences);
- inter-governmental liaison actions (local, municipal, national, international); and
- outreach (training programs, demonstration projects, etc.)

The above options must be evaluated on an ongoing basis in terms of their ability to promote promising projects. A structured program of data collection for monitoring the progress of the objectives may be developed in this regard. Once data has been collected, reviewed, and analyzed, an evaluation of the impact of the option can be made and the established objectives can be retained or modified as appropriate.

6.5 Obtain Project Funding

Each of the activities discussed above requires resources, as does the implementation of individual landfill gas recovery projects. This section lists steps for obtaining assistance from international funding agencies for these initiatives. The key steps are to review the types of assistance available, identify funding requirements, and select specific source(s) of funding. Once the appropriate source of funding has been identified, a project proposal can then be prepared in accordance with the specific criteria of the funding agency.

6.5.1 Review Types of Assistance Available

The first source of funding that countries should consider is forming a partnership with local and foreign private sector project developers. This method is often the quickest and cheapest method of obtaining funding. However, such funding is only available for projects that are clearly profitable. For projects with a lower economic rate of return, funding may be available from international agencies.

The main types of assistance offered by international funding agencies are grants, loans, and other packages (including loan guarantees, venture capital funds, and business consulting assistance). These types of assistance are available to both governments and businesses. In some cases, the government may reallocate the funds to eligible businesses. The funds provided may cover costs to conduct feasibility assessments, implement demonstration projects, or acquire equipment and technical expertise. The main types of financial assistance are further described below:

- **Grants.** These are direct monetary payments for specific projects that do not need to be reimbursed. For example, grants may be used to develop a demonstration project or to fund a training program to enhance local expertise.

- **Loans.** These are made by the funding agencies directly to the eligible parties and must be paid back in a specified period of time. Typical recipients of such loans may be government agencies (for direct use or reallocation to businesses); or businesses in manufacturing, industrial export/import services, or technology development.

- **Other.** Loan guarantees, venture capital funds, and business consulting services are some of the other types of assistance that are offered by these institutions. These are described below:

  - *Loan Guarantees* are commitments to repay the lender if the borrower defaults. In these cases, a funding agency guarantees its proportionate share of loss in accordance with the percentage of the guarantee. Loan guarantees are important to mitigate risk at projects that have a higher degree of risk.

  - *Venture Capital Funds* offer loans or equity to support the start-up of new businesses or expansion of existing businesses. Funding agencies may appropriate funds or generate funds from private investors by selling shares in the company.

- *Business Consulting Services* include technical, managerial, and financial consulting and support services. Typical sources of such assistance are governments, multilateral and bilateral agencies, and business- and research-related entities. Technical services may range from providing technology transfer to providing engineering assistance to offering use of research and development facilities. Managerial consulting includes offering seminars, workshops, and consultations on improving project operations. Financial consulting may involve assistance in creating packages to finance a project or group of projects.

6.5.2 Identify Funding Requirements

The type of funding required is driven primarily by two factors: the objectives of the program, and the country's resource allocation. These are briefly described below.

- **Program Objectives.** Government programs aimed at exploring the opportunities for landfill gas recovery (e.g., by conducting feasibility studies) would most likely seek grants or other concessional funds. On the other hand, businesses and government agencies pursuing profitable landfill gas recovery projects are eligible for loans, loan guarantees, and venture capital funding.

- **Resource Allocation.** The extent of economic development and resource endowments for a given country will determine its financial requirements. Countries with a low GNP per capita will typically require grants to undertake landfill gas recovery projects. Some countries may face difficulty when securing loans, if they have creditworthiness problems.

Once the funding requirements have been assessed, the next step is to identify the funding available.

6.5.3 Select Sources of Funding

There are a wealth of possible funding sources which provide assistance that can be used for landfill gas recovery projects. These include multilateral institutions, regional development banks, U.S. government agency programs, country- and region-specific enterprise funds, and other institutions. Exhibit 6-5 lists funding sources most applicable to landfill gas recovery projects, and summarizes the types of funding offered by each. Summary profiles of the funding agencies are presented in Appendix B. The main categories of funding sources are briefly described as follows:

- **Private Sector.** Funding may be available from private sector associations or firms interested in landfill gas recovery. Such funding is most commonly available for projects with a high expected rates of return and usually takes the form of a profit-sharing partnership. This method is often the quickest and cheapest method of obtaining project funding.

- **World Bank Institutions.** The World Bank institutions fund environmental and energy infrastructure projects in developing countries for which the procurement of technical assistance, civil works, materials and equipment, are necessary. These agencies provide grants and loans to government ministries and businesses, which implement projects under local procurement and contracting regulations. Examples of such institutions include the World Bank itself (also known as the International Bank for Reconstruction and Development), International Finance Corporation (IFC), and the Global Environment Facility (GEF).

- **Multilateral Development Banks.** These are international lending institutions owned by member countries that promote economic and social development in developing member nations by providing loans, technical assistance, capital investment, and help with economic development plans. Examples of such institutions include the Asian Development Bank (ADB), the European Bank for Reconstruction and Development (EBRD), and the Inter-American Development Bank (IDB).

- **U.S. Government Agency Programs.** There are several U.S. government agencies that promote development by funding feasibility studies, training programs, and seminars in developing countries. In most cases, these agencies/programs support projects that offer export or investment potential for U.S. enterprises. Examples of such agencies/programs include the Trade Development Agency (TDA) and the Overseas Private Investment Corporation (OPIC).

- **U.S. Initiative on Joint Implementation (USIJI):** The USIJI is a voluntary private program that provides recognition and select technical assistance to U.S. companies implementing greenhouse gas reduction projects in other countries. While no funding is available through the USIJI, projects that meet the USIJI criteria will be likely to attract U.S. investors solely on the recognition of USIJI acceptance.

For more information on the types of funding available and sources of funding for landfill gas recovery projects contact:

NEXT STEPS

U.S. Environmental Protection Agency
Methane Branch
Mail Code 6202 J
401 M Street, S.W.
Washington D.C. 20460
Tel: 202/233-9768
Fax: 202/233-9569

Exhibit 6-5: Summary Table of Promising Sources of Funding and Other Assistance

Name of Agency	Type of Assistance Provided			Comments
	Grants	Loans	Other†	
World Bank Agencies/Programs				
International Bank of Reconstruction and Development (IBRD)		✓	✓	The World Bank finance capital infrastructure projects through the International Bank for Reconstruction and Development (IBRD) and its affiliates - IFC, IDA, and MIGA.
Global Environment Facility	✓		✓	GEF funds the difference between expected project revenues and project costs. Therefore, GEF funding is ideal for conducting feasibility assessments.
International Finance Corporation (IFC)		✓	✓	IFC provides loans and other financial packages to private sector enterprises only. The minimum support provided by IFC is $10 million.
Solar Initiative	✓	✓	✓	The Solar Initiative promotes the application of solar, wind, and biomass energy by providing assistance to energy industry, research, and NGOs in developing countries
Multilateral Development Banks				
European Bank For Reconstruction and Development (EBRD)		✓	✓	EBRD provides loans, equity, and guarantees to Central and Eastern European countries for developing into market-based economies.
Inter-American Development Bank (IDB)	✓	✓	✓	IDB provides loans for development projects in Latin America and the Caribbean. Grants are available for poorer member countries.
Asian Development Bank (ADB)	✓	✓	✓	ADB provides loans for the economic and social advancement of member countries. Concessional funds are available through special funds established by the ADB.
Africa Development Bank (AfDB)	✓	✓	✓	AfDB provides loans for the economic and social advancement of African countries. Grants are available for the poorest countries through special funds.
U.S. Government Agency Programs				
Trade Development Agency	✓		✓	TDA provides funding to projects in developing countries that offer export or investment potential for U.S. enterprises. The average grant size ranges from $300,000 to $400,000.
United States Agency For International Development (USAID)	✓		✓	USAID's Office of Environment, Energy, and Technology assists in developing market-based solutions to environmental problems in developing countries.
Overseas Private Investment Corporation (OPIC)		✓	✓	OPIC provides funding by facilitating U.S. private investment in developing countries through loans, loan guarantees, and special services.
Export-Import Bank (EXIMBANK) of the United States		✓	✓	EXIMBANK provides loans and guarantees to foreign buyers of U.S. goods and services. The bank finances up to 85% of the U.S. export value.
U.S. Initiative on Joint Implementation (USIJI)			✓	Projects that meet the USIJI criteria are likely to attract U.S. investors seeking to obtain recognition and other amenities available to U.S. participants in the USIJI program.

† This includes loan guarantees, venture capital funds, consulting services etc.

NEXT STEPS

6.6 References

Watts, Robert A., (1995) *Profitable Market Opportunities for Pollution Prevention - International Market Opportunities*, Presentation for US EPA Atmospheric Pollution Prevention Division Forum, April 10, 1995, Washington D.C.

APPENDIX A: DIRECTORY OF SELECT LANDFILL GAS RECOVERY EXPERTS IN THE U.S.

NOTE: Mention of company names in this document does not constitute the U.S. EPA's endorsement.

	Name	Address	Contact Person	Area(s) of Expertise
1.	CH2MHILL	P.O. Box 4400 Reston, VA 22090	Thomas Kraemer, Senior Engineer Tel.: (703) 471-6405; Extension.43, Fax: (703) 481-0980	Engineering consulting: landfill gas flow estimation, gas collection system design and energy recovery design in Turkey, Hong Kong and the U.S.
2.	Curtis Engine & Equipment	3918 Vero Road, Suite Baltimore, MD 21227-1516	Richard L. Ay, Senior. Vice President Tel.: (410) 536-1203; Fax: (410) 536-2098	Gas well monitoring and management, gas processing, compressors, and power generation.
3.	Ecogas, Inc.	6300 Bridgepoint Parkway, #300 Austin, TX 78730	Jerrel Branson, President Tel.: (512) 338-9874 Fax: (512) 338-4569	Landfill gas conversion into vehicle fuel. Active in both the U.S. and Latin America
4.	HDR Engineering, Inc.	12700 Hillcrest Road, Suite 125; Dallas, TX 75230	Jack Blenk, Senior Landfill Consultant Tel.: (214) 960-4400 Fax: (214) 960-4471	Landfill gas migration investigation; landfill gas flow estimation, monitoring, and venting; design of electrical power generation facilities, including internal combustion engines and/or generators. Have worked on projects in numerous countries.
5.	Jenbacher Energie	1502 Providence Highway, Suite 2 Norwood MA 02062	Werner Faass Tel: (617) 255-5886 Fax: (617) 255-5887	Supply of internal combustion engines and turbines to landfill gas-to-energy projects. Have worked in Brazil and Costa Rica, among other countries.
6.	Laidlaw Gas Recovery Systems, Inc.	39899 Balentine, #275 Newark, CA 94560	George R. Jansen, Vice President Tel.: (510) 661-2302 Fax: (510) 661-2320	Fully cognizant in all aspects of landfill gas development.
7.	Landfill Control Technologies(Landtec)	6055 E. Washington Commerce, CA 90040	Alex Roqueta, Vice President Tel.: (213) 722-8202 Fax: (213) 725-8772	Landfill gas energy recovery project development--design, installation, and operation at several sites in the United States and a few in developing countries.
8.	Maguire Group, Inc.	225 Foxborough Road Foxborough, MA 02036	Robert Watts Tel.: (508) 543-1700 Fax: (508) 543-5157	Project feasibility analysis, project design, and project development. Have worked on projects in Turkey, Czech Republic and Romania
9.	Organic Waste Technologies	2 Southcross Trail Fairport, NY 14450	Barry Rogers, Energy Development Manager Tel: (716) 425-3436 Fax: (716) 425-7116	Landfill gas-to-energy project development - design, installation and negotiation of projects. Active in Costa Rica, Hong Kong, and Korea.
10.	RUST Environment & Infrastructure	1240 E. Diehl Road Naperville, IL 60563	Chuck Anderson, Senior Project Manager Tel.: (708) 955-6666 Fax: (708) 955-6601	All phases of project development including field testing, feasibility studies, design, permitting, equipment procurement, construction, start-up, system operation, and troubleshooting. Active in the U.S., in Hong Kong, Israel, and Italy.
11.	SCS Engineers	2060 Reading Road Cincinnati, OH 45202	James J. Walsh, Senior Vice President Tel.: (513) 421-5353 Fax: (513) 421-2847	Due diligence investigations, feasibility and market assessments; system design, collection, installation, operation and maintenance. Active in the U.S., Canada, Mexico, the Caribbean Basin, Europe, Asia, and Australia.
12.	Terameth Industries	1331 N. California Blvd., Suite 730 Walnut Creek, CA 94596-4502	Gil Cervantez, Executive Vice President Tel.: (510) 939-2020 Fax: (510) 939-2052	Utilization of landfill gas for the production of methanol. Experience in the U.S. only.

APPENDIX B: DIRECTORY OF POSSIBLE FUNDING AGENCIES

Profiles of the following funding agencies are provided:

World Bank Agencies/Programs

International Bank of Reconstruction and Development (IBRD)

Global Environment Facility (GEF)

International Finance Corporation (IFC)

Solar Initiative

Multilateral Development Banks

European Bank For Reconstruction and Development (EBRD)

Inter-American Development Bank (IDB)

Asian Development Bank (ADB)

Africa Development Bank (AfDB)

U.S. Government Agency Programs

Trade Development Agency (TDA)

United States Agency For International Development (USAID)

Overseas Private Investment Corporation (OPIC)

Export-Import Bank (EXIMBANK)

U.S. Initiative on Joint Implementation

International Bank of Reconstruction and Development (IBRD)

Overview: The World Bank, established in 1945, comprises the International Bank for Reconstruction and Development (IBRD) and its affiliates: the International Development Agency, the International Finance Corporation (IFC), and the Multilateral Investment Guarantee Agency (MIGA). 155 member countries have subscribed capital to the Bank enabling it to finance its lending operations primarily from its own borrowing in capital markets. However, a substantial portion of the IBRD's resources also come from the retained earnings and the flow of repayment.

The World Bank, through its affiliates IBRD, IDA, IFC, and MIGA, provides financial assistance to developing countries for social and economic development projects.

The World Bank finances capital infrastructure, such as roads and railways, telecommunications, and port and power facilities. However, the Bank's development strategy emphasizes investments that can directly affect the well-being of poor people in developing countries by making them more productive and integrating them as active partners in the development process. The Bank's efforts to reduce poverty include investments to improve education, ensure environmental sustainability, expand economic opportunities, strengthen population-planning, health and nutrition services, and develop the private sector.

Criteria: The IBRD's charter requires that it: (1) lend for productive purposes to stimulate economic growth in developing countries; (2) pay due regard to the prospects of repayments; (3) make loans to governments or with guarantees from the government; (4) not restrict procurement to purchases from any particular member country; and (5) make lending decisions on economic considerations alone.

The IDA provides assistance to poorer developing countries, i.e., those with an annual per capita gross domestic product of $580 or less, expressed in 1989 U.S. dollars. Terms of the IDA loans are less stringent than those of "regular" IBRD loans.

The IFC is legally and financially a separate entity. Its purpose is to promote growth in the private sector of the less developed country economies, largely by taking equity positions in projects (see profile).

The MIGA encourages equity investment and other direct investment through the mitigation of non-commercial investment barriers. MIGA must: (1) offer investors guarantees against non-commercial risks; (2) advise developing member countries on policies, programs, and procedures related to foreign investment; and (3) sponsor a dialogue between the international business community and host governments on investment issues.

Contact Information: For further information, contact

The World Bank
1818 H Street, N.W.
Washington D.C. 20433 USA
Tel: 202/477-1234

Global Environment Facility (GEF)

Overview: The Global Environment Facility (GEF), an organization established by the United Nations Development Program (UNDP), the United Nations Environment Program (UNEP), and the World Bank, offers grants and concessional funds to developing countries for projects that are beneficial to the global environment. GEF funds are used to cover the difference between the costs of a project undertaken with global environmental objectives in mind, and the costs of an alternative project that the country would have implemented in the absence of global environmental concerns. GEF resources are available to projects that address the following four areas: climate change, loss of biological diversity, pollution of international waters, and depletion of the ozone layers. Listed below are several types of projects that the GEF may fund.

GEF will fund only those projects which cannot pay for themselves, i.e., whose project costs exceed project revenues. Therefore, GEF funding is ideal for conducting feasibility assessments.

- Technical assistance projects focused on human development, capacity building, training, and information sharing;
- Feasibility studies for investment projects and complex technical assistance projects;
- Small grants for community-based grassroots organizations and non-governmental organizations in developing nations; and
- Grants to investment projects to fund the incremental costs of achieving global environmental benefits.

Criteria: The GEF has established general criteria for all areas in which it may fund projects, as well as criteria specific to each of the four areas. The general points which are assessed include:

- Potential to benefit the global environment;
- Contribution to human welfare and sustainable development;
- Financability of project without GEF support;
- Scientific and technical basis of project;
- Plans for evaluation and dissemination of results;
- Host nation political, legal, economic, and administrative conditions under which the project must be executed
- Development of human and institutional resources;
- Plans for post-GEF project continuation; and
- Involvement of local communities.

Contact Information: For further information, contact the GEF at:

GEF Administrator, Environment Department
World Bank
1818 H Street, N.W.
Washington, DC 20433
Tel.: 202/473-1053
Fax: 202/477-0551

International Finance Corporation (IFC)

Overview: The International Finance Corporation (IFC) was established in 1956 to help strengthen the private sector in developing countries. IFC lends directly to the private sector. IFC aids private sector development by providing long-term loans, equity investments, guarantees and "stand-by financing", risk management and "quasi-equity instruments", such as subordinated loans, preferred stock, and income notes. IFC advisory services and technical assistance help private business increase their chances of success. Other relevant information on IFC is as follows:

- *Source of funds*: About 80% is borrowed in the international financial markets through public bond issues private placements and 20% is borrowed from IBRD;
- *Lending*: Each year, IFC approves about $4 billion in financing, including syndications and underwriting for private-sector projects in developing countries. The minimum amount of IFC support available is $10 million; and
- *Loan Conditions*: Interest rate on IFC loans and financing are based on market rates, which vary between countries and projects; maturity on loans ranges from 3 to 13 years.

IFC will provide loans and other financial instruments (equity investments, guarant- ees, etc.) to the private sector only. The minimum support provided by IFC is $10 million.

Criteria: Project proposals will be assessed on the basis of the following information:

- *Project Description*: brief description of the project and current status;
- *Sponsorship and Management*: history and business of sponsors, management arrangements, and technical arrangements;
- *Markets and Sales*: market orientation (export/domestic), production volumes and sales objectives, potential users and distribution channels, and relevant tariffs and protective measures;
- *Technical Feasibility*: equipment availability, labor and infrastructure facilities, resource accessibility, and potential environmental issues;
- *Financing Requirements*: breakdown of project costs, proposed financial plan, type of assistance sought, and expected profitability;
- *Government Regulations*: government controls, exchange controls, tax regulations, export/import licences, and price controls applicable to the project.

Contact Information: For further information, contact the IFC at:

International Finance Corporation
1850 I (Eye) Street, N.W.
Washington, D.C. 20433
Tel.: 202/477-1234
Fax: 202/477-6391

Solar Initiative (A World Bank Program)

Overview: The Solar Initiative is a World Bank program aimed at providing assistance to energy industry, research, and non-governmental organization (NGO) communities in developing countries to promote the use of solar and other renewable energy technologies. The two main thrusts of the initiative include: 1) the preparation and finance of commercial and near commercial applications; and 2) facilitation of international research, development, and demonstration.

The World Bank's role is to facilitate and finance projects under the Solar Initiative by leveraging its resources. Funding under the Solar Initiative is provided thorough various divisions of the World Bank including the Global Environmental Facility (GEF) and International Finance Corporation (IFC). The relevant parties in the host country (e.g., energy sector operating divisions) play a key role in project identification and preparation efforts to reach the investment stage.

The Solar Initiative promotes the application of solar, wind, and biomass energy by providing assistance to energy industry, research and NGO communities in developing countries.

Criteria: The Solar Initiative provides assistance solely for renewable energy applications that are important for developing countries, but for various reasons have not received significant attention in the regular lending program. These include: solar, wind, and biomass energy applications. Large-scale hydroelectric projects, however, are excluded as these are a long established application. Specific examples of projects include:

- *Biomass*: industrial scale methane generation from animal and distillery wastes;
- *Wind*: installation of wind farms and other large grid-connected power applications; and
- *Solar*: use of photovoltaic (PV) power for rural applications such as lighting, water pumping, battery charging, and vaccine refrigeration.

Contact Information: For further information, contact:

Energy Practice Manager
The Solar Initiative
The World Bank Group
Washington, D.C. 20433
Tel.: 202/477-1234
Fax: 202/477-6391

European Bank for Reconstruction and Development (EBRD)

EBRD provides loans, equity, and guarantees to countries of central and eastern Europe that are developing into market-based economies.

Overview: The European Bank for Reconstruction and Development (EBRD) is a multinational institution set up with the specific aim of assisting countries of central and eastern Europe to develop into market-oriented economies. The EBRD provides financial assistance to both the private and public sector. The types of financial instruments offered include: loans; equity and quasi-equity investments; and guarantees. Other information about EBRD financing:

- *Minimum Loan Amount*: The minimum lending requirement for the Bank is ECU 5 million ($6.5 million, as of November 1995).
- *Interest Rates*: Interest rates are set at a margin over a market benchmark (usually LIBOR - London Interbank Offered Rate). Loans can be either variable rate or fixed rate;
- *Loan Term*: Maturities generally range from 5 to 10 years, depending on the individual operation requirements; and
- *Currency*: The EBRD lends in hard currencies - US dollar, the Deutschmark, and the ECU.

Criteria: The first step in the approval process is the *Concept Clearance* stage. Prospective borrowers approach the banking staff to advise on procedure and potential structuring options. Based on information on the scope of the project, financing requirements, and technical and economic/commercial aspects, the Bank will determine whether the project fits within its guidelines and strategies.

If the project is cleared, a *Mandate Letter*, defining the legal requirements for entering to a relationship with the Bank, is signed and an *Operation Leader* is assigned as the key Bank contact for the project. The next stage is the *Initial Review* which requires detailed project information, including:

- detailed description of the enterprise, project, and key personnel;
- financial statements audited to international standards;
- financial projections about the viability of the project;
- regulations applicable to the project; and
- assessment of the environmental impact of the project.

Once the project has cleared Initial Review, it has to pass Final Review by the Bank's Operation Committee. This evaluation process covers financial, legal, economic , technical, and environmental issues.

Contact Information: For further information, contact:

EBRD, One Exchange Square
London EC2A 2EH, United Kingdom
Tel: 44 71 338-6282
Fax: 44 71 338-6102

Inter-American Development Bank (IDB)

Overview: The Inter-American Development Bank (IDB) is a multilateral development bank created to help accelerate the economic and social development of its member countries in Latin America and the Caribbean. The IDB provides the following types of assistance to its member countries: loans and other financial instruments; concessional funds for needier countries (through its Fund of Special Operations); and technical assistance to strengthen regional development institutions and help identify and implement investment projects. Other relevant information about the IDB is as follows:

- *Extent of Financing*: The IDB finances a certain percentage of project costs, ranging from 50% for more economically developed countries to 80% for poorer countries.
- *Loan Conditions*: Interest rates on IDB loans and financing are based on market rates, which vary between countries and projects; maturity on loans ranges from 15 to 25 years.
- *Capital Resources*: The IDB has a capitalization of over $100 billion that can support a level of annual lending of over $7 billion .

Typical borrowers of IDB funds include governments, ministries, or an agency or utility under a ministry. The borrower makes the key decisions on awarding contracts for engineering, design, project management, works construction, and purchase of capital goods. While governments and related agencies are the primary recipients of IDB funds, private sector enterprises too are eligible for some forms of assistance.

IDB provides loans to governments and private sector agencies for social and economic development projects in Latin America and the Caribbean. Grants are available for poorer member countries.

The IDB has an Environmental Division that monitors the environmental component of the Bank's operations and develops loans and technical assistance packages specifically directed towards protecting the environment.

Criteria: The following analyses are conducted to evaluate project proposals:

- *Institutional*: borrower's administrative and operational capability to carry out the project;
- *Technical*: technical equipment, labor, and infrastructure required;
- *Socio-economic*: social and economic costs and benefits, impacts on trade, income distribution, production, and employment; and
- *Environmental*: environmental impacts of the project.

Contact Information: For further information, contact:

Inter-American Development Bank
1300 New York Avenue, N.W.
Washington D.C. 20577 U.S.A
Tel: 202/623-1000
Fax: 202/623-3096

Asian Development Bank (ADB)

Overview: Established in 1966, the Asian Development Bank (ADB) is a multilateral development bank whose primary objective is poverty alleviation through sustainable economic growth in Asia. The Bank has 35 developing member countries, of which China, India, and Indonesia are the largest recipients. ADB assistance is channeled into the following sectors: agriculture and agro-industry; energy; industry and non-fuel minerals; financial services; transport and telecommunications; social infrastructure (e.g., education, health); and urban development.

ADB provides loans for the economic and social advancement of developing member countries. Grants are available through special funds established by the ADB (e.g., ADF, ALGAS).

Typical borrowers of ADB funds include governments, ministries, or an agency or utility under a ministry. The borrower makes the key decisions on awarding contracts for engineering, design, project management, works construction, and purchase of capital goods. While governments and related agencies are the primary recipients of ADB funds, private sector enterprises too are eligible for some forms of assistance. For private sector support, a project must play a catalytic role in the development of the country. For such projects, ADB assistance is limited to 50% of project costs or up to $50 million, whichever is less. The minimum loan is $5 million.

The financial resources of the Bank consist of ordinary capital resources comprising subscribed capital from member countries, reserves and funds raised through borrowings; and Special Funds, including the Asian Development Fund, which is made up of contributions from member countries and other accumulated income; and the ALGAS fund, which is designed to support GHG mitigation activities in developing member countries.

Criteria: The projects or programs are analyzed in terms of:

- the borrower's capacity to finance and administer the project;
- its economic, technical, and environmental feasibility; and
- its social and economic benefits to the recipient country.

Contact Information: For further information, contact:

Asian Development Bank
Office of the Environment and Social Development
6 ADB Avenue, 1501 Mandaluyong City
0401 Metro Manila, Philippines
Tel.: 632/813-2148
Fax: 632/741-7961

African Development Bank (AfDB)

Overview: The African Development Bank (AfdB) is a multilateral development bank whose primary objective is to finance economic and social development in African countries. It achieves this objective through the provision of: loans and other financial instruments; technical assistance and institutional support; and mobilization of external resources for investment in Africa. Grants and other concessional funds are allocated for the poorest countries through the African Development Fund (ADF) and the Nigeria Trust Fund (NTF). The main criteria for defining the poor countries is GNP per capita. The loan terms are as follows:

Terms	AfDB	ADF	NTF
Interest Rate	Variable†	None	4%
Service Charge	1%	0.75%	0.75%
Repayment Period	20 years	50 years	25 years

† The interest rate is reviewed every 6 months. As of June 30, 1995, the rate was 7.42%

Typical borrowers of AfDB funds include governments, ministries, or an agency or utility under a ministry. While governments and related agencies are the primary recipients of AfDB funds, private sector enterprises too are eligible for some forms of assistance. For private sector support, AfDB assistance is limited to a third of project costs. The size of private sector loans are generally in the $100,000 to $10 million range.

AfDB provides loans for the economic and social advancement of African countries. Grants are available for the poorer countries through the Africa Development Fund and the Nigeria Trust Fund.

Criteria: The AfDB approves projects or program financing only on the basis of appraisal reports prepared and submitted by the Bank's own staff, even where a project have been previously appraised by other co-financing institutions. The appraisal process accounts for the following:

- the borrower's administrative and operational capability to carry out the project;
- technical equipment, labor, and infrastructure required and available; and
- social and economic costs and benefits.

Contact Information: For further information, contact:

African Development Bank
01 BP 1387 Abidjan 01
Cote d'Ivoire, Africa
Tel: 225/20 41 18
Fax: 225/20 40 06

Trade Development Agency (TDA)

Overview: Established in 1980, the U.S. Trade Development Agency (TDA) is a government organization that promotes U.S. exports by providing grants for feasibility studies for large development projects in developing and middle income countries. The purpose of these grants is to provide U.S. firms with the opportunity to undertake feasibility studies for large overseas projects, thereby increasing the chance that they will be involved in project implementation. TDA grants the funds on the condition that U.S. firms are utilized to conduct the study. TDA is currently involved in: energy, environment, mining and minerals development, health care, manufacturing, telecommunications, transportation, water resources, agriculture, and aviation.

TDA will provide grants to conduct feasibility studies in developing countries on the condition that U.S. firms be hired to conduct the study. The average grant size ranges from $300,000 to $400,000.

There are two types of studies which the TDA may fund: (1) feasibility studies for projects in which U.S. companies intend to make equity investments, and (2) feasibility studies for public sector projects. Before TDA funds a feasibility study, experts are hired to develop reports regarding the feasibility study and the project to be implemented at the conclusion of the study. If the TDA decides to fund the feasibility study, it asks interested firms to submit proposals. The host government decides which of the competing companies will undertake the study.

The agency may provide up to one million dollars per study, although the average grant amount ranges between $300,000 and $400,000. While up to 20 percent of the TDA funding may be used to pay subcontractors in the host country, the remainder must be used for services sourced in the U.S.

Criteria: All feasibility study proposals must include the following information: project description; U.S. export potential; information on host country partners; evidence of the host nation's commitment to the project; justification for why TDA funding is needed; a financial analysis of the project; an assessment of foreign competition for project implementation; and the impact of the project on U.S. labor. A few of the most important criteria include:

- The project must be a development priority for the host country.
- The export potential of the project must be significantly greater than the cost of TDA assistance.
- The procurement process must be open to U.S. firms.

Contact Information: For further information, contact the TDA at:

Trade Development Agency
Room 309, SA-16
Washington, D.C. 20523-1602
Tel.: 703/875-4357
Fax: 703/875-4009

U.S. Agency for International Development (USAID)

Overview: USAID's Office of Energy, Environment, and Technology assists developing countries and emerging economies find market-oriented solutions to their energy and environmental problems. The Office's programs address three main issues: 1) high rates of energy demand and economic growth accompanies with lack of energy, especially in rural areas; 2) financial problems, including lack of investment capital; and 3) growing environmental threats, especially global climate change, acid rain, and urban air pollution. The Office focuses its efforts in the following areas:

- Energy Efficiency
- Renewable Energy Project Development
- Private Sector Energy Development
- Energy Technology Innovation
- Training/Technical Assistance

The Office has two main strategies for achieving its objectives:

- *Tapping U.S. Know-how:* The Office arranges cooperative relationships between developing countries and U.S. energy and environment industries, multilateral development banks, and non-governmental organizations; and
- *Promoting Private Sector Initiatives*: The Office assists countries put in place market-oriented policies and institutions to support private environment and energy initiatives.

USAID's Office of Energy, Environment, and Technology provides grants and technical assistance to developing countries for meeting their energy and environmental needs.

The types of assistance offered include: financing (loans, investment funds); policy, legislative, and regulatory development assistance; reports and workshops on market conditions and opportunities; and engineering and other technical assistance.

Criteria: The criteria for USAID fund varies on a case-by-case basis. However, the following points are generally considered in the project evaluation process:

- Potential of the project to meet its goals
- Contribution to human welfare and sustainable development;
- Scientific and technical basis of project;
- Host nation political, legal, economic, and administrative conditions

Contact Information: For further information, contact:

U.S. AID: Office of Energy, Environment and Technology
Room 508, SA -18
Washington D.C. 20523-1810
Tel.: 703/528-4488
Fax: 703/528-2280

Overseas Private Investment Corporation (OPIC)

Overview: OPIC is a U.S. government agency that provides loans, loan guarantees, and political insurance to American business ventures in the developing world. These services are provided to those projects that are economically and technically sound but are unable to receive sufficient financing or insurance from the commercial sector. Projects supported by OPIC must have a positive effect on the U.S. economy, be financially sound, and provide significant benefits to the social and economic development of the host nation. While OPIC does not require the foreign enterprises to be owned entirely by U.S. interests, generally the U.S. investor is expected to own at least 25 percent of the equity in the project. Neither financing nor insurance will be available for investments in business that are majority owned by a foreign government. Furthermore, only the portion of the investment made by a U.S. investor may be insured by OPIC.

OPIC will provide loans and loan guarantees for projects in developing countries that US enterprises have a stake in. The project must have a positive effect on the US economy.

OPIC's finance division offers loans and loan guarantees. Loans are generally granted to small U.S. businesses and range from $2 million to $10 million. For larger projects, in the $10 million to $75 million range, loan guarantees are provided. OPIC's insurance division offers coverage against the following three risks: currency inconvertibility, expropriation, and political violence. Other investor services provided by OPIC include investment missions and outreach activities.

Criteria: Eligible projects must meet the following criteria:

- Positive effect on the U.S. economy: Projects must demonstrate positive balance of payments and employment effects on the U.S. economy;
- Development contribution: Projects must benefit the economic and social development of the host nation;
- Performance requirements: OPIC will not become involved in any project subject to performance requirements that will reduce the potential for U.S. trade and employment benefits.
- Environmental impact: the project should not have an unreasonable or major adverse impact on the host nation's environment; and
- Worker's rights: All projects supported by OPIC must meet internationally recognized standards with regards to worker's rights.

Contact Information: For further information, contact OPIC at:

Overseas Private Investment Corporation
1100 New York Avenue, N.W.
Washington, D.C. 20527
Tel.: 202/336-8799
Fax: 202/408-9859
Fax-ion-Demand System: 202/336-8700

Export-Import Bank (EXIMBANK)

Overview: The Export-Import Bank (EXIMBANK) of the United States is a U.S. Government agency that facilitates the export financing of U.S. goods and services to foreign buyers. EXIMBANK supports export sales by providing direct loans to foreign buyers, guarantees to U.S. and foreign commercial lenders for credit risk protection, export credit insurance, to U.S. exporters against failure of foreign buyers to meet payment obligations, and pre-export financing for small business through its Working Capital Guarantee Program.

Relevant information about EXIMBANK loans includes:

- *Types of Loans*: EXIMBANK provides both direct and intermediary loans. Direct loans are provided to foreign buyers of U.S. exports; intermediary loans fund parties that extend loans to foreign buyers;
- *Interest Rates*: EXIMBANK loans carry the lowest interest rate permitted under the OECD Arrangement for the market and term. , this rate is the OECD Commercial Interest Reference Rate (CIRR), which changes monthly. For relatively poor countries, lower interest rates loans are available; and
- *Extent of Assistance*: Loan and guarantee programs cover up to 85% of the U.S. export value.

EXIMBANK provides loans and guarantees to foreign buyers of US goods and services. The bank covers up to 85% of the US export value.

Criteria: Transactions are evaluated in terms of the creditworthiness of the buyer, the buyers country, and the exporters ability to perform. In general the following information is assessed:

- *Financial Data*: Balance sheets and income statements for the past 3 years for the buyer and any guarantor(s);
- *Credit Data*: at least two credit references are checked;
- *Technical Feasibility*: technical characteristics of the project, breakdown of costs, project scheduling, participant profiles, environmental aspects, etc.; and
- *Applicant and Exporter Data*: Evidence of the applicants ability to implement the requested loan or guarantee.

Contact Information: For further information, contact:

Export-Import Bank of the United States
Credit Information Section
811 Vermont Avenue, N.W.
Washington D.C. 20571
Tel: 202/377-6336
Fax: 202/566-7524
Fax -on-Demand system: 800/424-5201

U.S. Initiative on Joint Implementation (USIJI)

Projects that meet the USIJI criteria are likely to attract US investors seeking the recognition and other amenities available to participants in the USIJI program.

Overview: The U.S. announced its Initiative on Joint Implementation (USIJI) in October 1993. This voluntary pilot program provides recognition and select technical assistance to U.S. greenhouse gas reduction projects in other countries. This program allows U.S. companies to reduce emissions at a lower cost than would be incurred by projects undertaken at home. U.S. government agencies involved in this program include the Environmental Protection Agency, the Department of Energy, the Department of State, the Agency for International Development, the Department of Commerce, and the Department of Agriculture, among others.

The benefits of this program to U.S. participants include public recognition, including use of the USIJI logo and media events, and technical assistance. This assistance may include help in obtaining host country acceptance of the project, identifying or developing methodologies for establishing a greenhouse gas emissions baseline, and guidance on how to monitor and verify emissions reduced or sequestered. For foreign participants, the benefits may include technology transfer, investments in technologies that benefit the global environment as well as the local economy, employment opportunities and training, and local environmental benefits.

Eligible program participants include U.S. citizens, U.S. companies, and any U.S. federal, state, and local government entity. Foreign partners may include private citizens and public entities of all nations that have ratified the United Nations Framework Convention on Climate Change (UNFCCC).

Criteria: Projects accepted into the USIJI program must:

- obtain host country acceptance;
- prove that the specific measures to reduce or sequester greenhouse gases are being undertaken as a result of USIJI or in its anticipation;
- provide sufficient and reliable data to establish a baseline of current and future greenhouse gas emissions;
- provide for the tracking of emissions reduction or sequestration;
- allow for external verification of emissions reduction or sequestration;
- identify benefits or negative effects on the economic and social development of the host country and on the local environment.

Contact Information: For further information, contact:

The USIJI Secretariat
600 Maryland Avenue, SW Suite 200 East
Washington, D.C. 20585
Tel.: 202/426-0072
Fax-on-Demand System: 202/260-8677