CHAPTER 1

Basic Concepts of Integrated Solid Waste Management

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

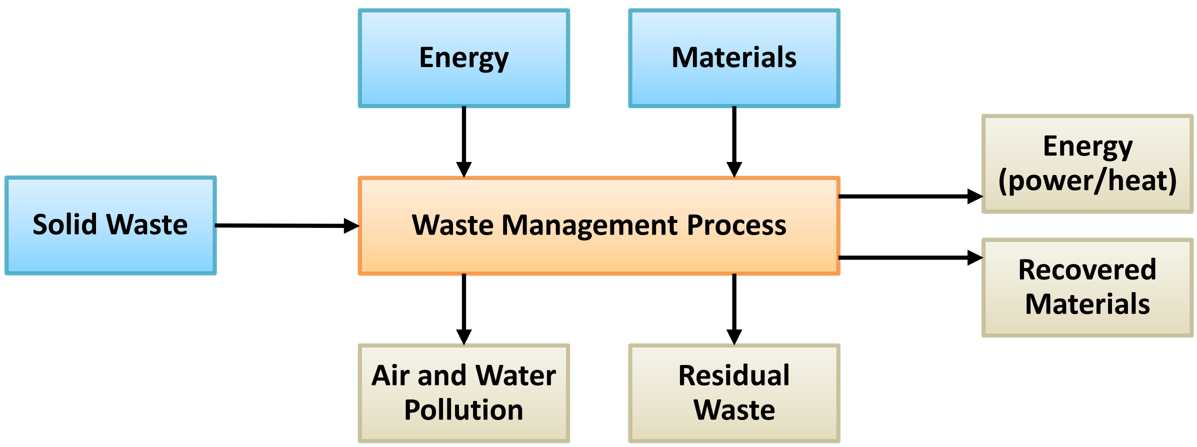

Figure 1-1. Life Cycle Inputs and Outputs of a Waste Management Process

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

[1] Population Reference Bureau. April 2011. *World Population*. http://www.prb.org/.
[2] UN-HABITAT. 2010. *Solid Waste Management in the World's Cities, Water and Sanitation in the World's Cities*. http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2918.
[3] Ibid.

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

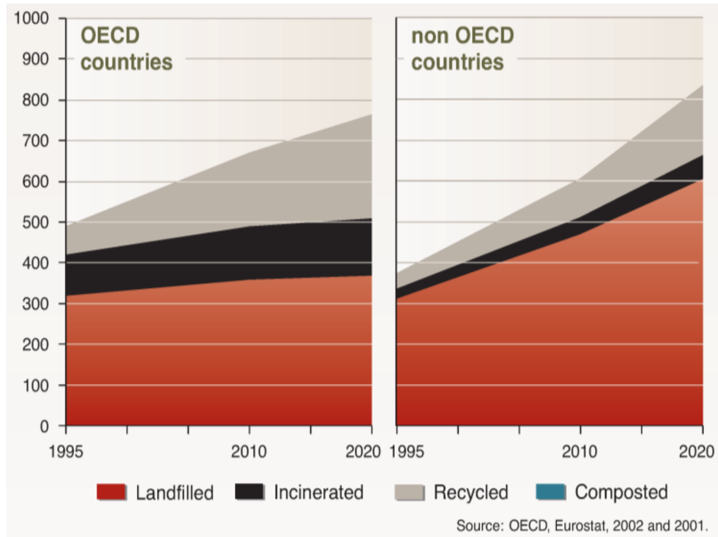

Figure 1-2. Increased Waste Generation in Developing Countries Predicted for 2020[5]

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

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

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

[4] U.S. EPA. Methane: Science – Global Warming Potentials. http://www.epa.gov/methane/scientific.html.

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

[6] U.S. EPA. 2011. *DRAFT: Global Anthropogenic Emissions of Non-CO$_2$ Greenhouse Gases: 1990–2030*. EPA 430-D-11-003. http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html.

[7] USAID. November 2004. *Draft Final: Study of the Market Potential for Recovered Methane in Developing Counties.* http://pdf.usaid.gov/pdf_docs/PNADK799.pdf.

[8] The World Bank. 2011. Analysis of Technology Choices. http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/EXTUSWM/0,,contentMDK:20239704~menuPK:497751~pagePK:148956~piPK:216618~theSitePK:463841,00.html.

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

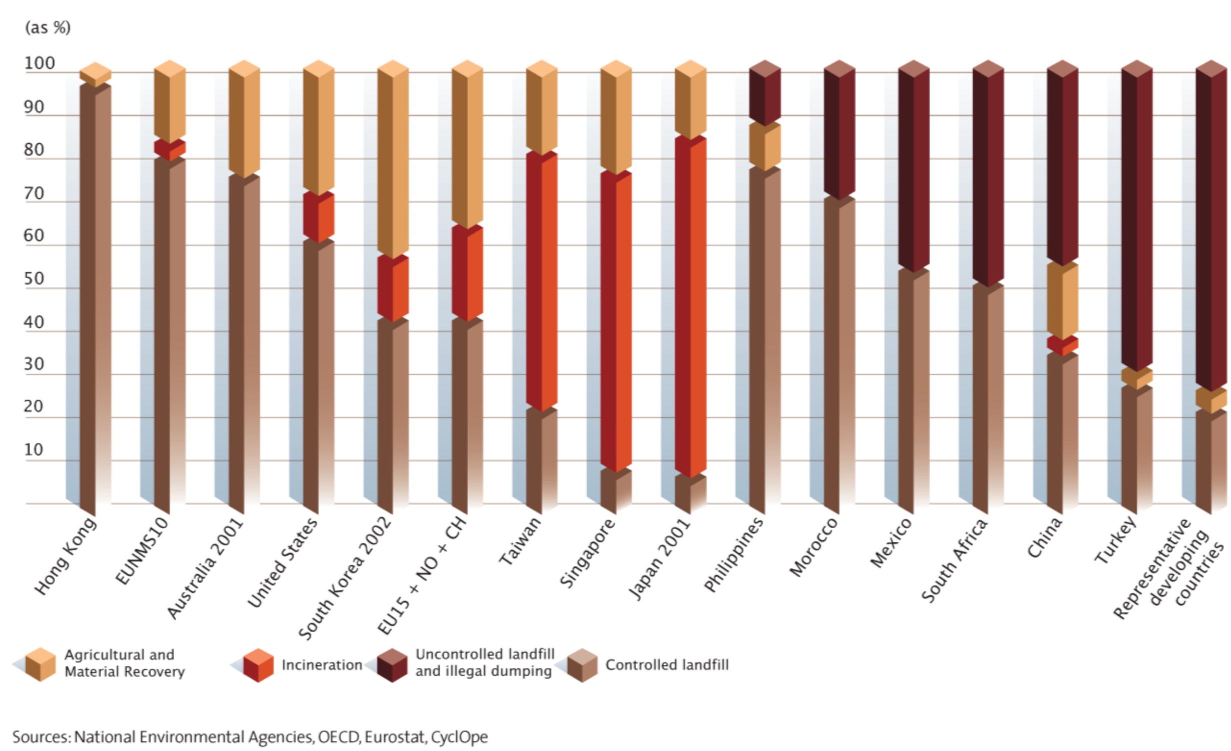

Figure 1-3. Municipal Waste Treatment Practices for Select Countries[11]

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

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

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

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

Major Components of Integrated Solid Waste Management

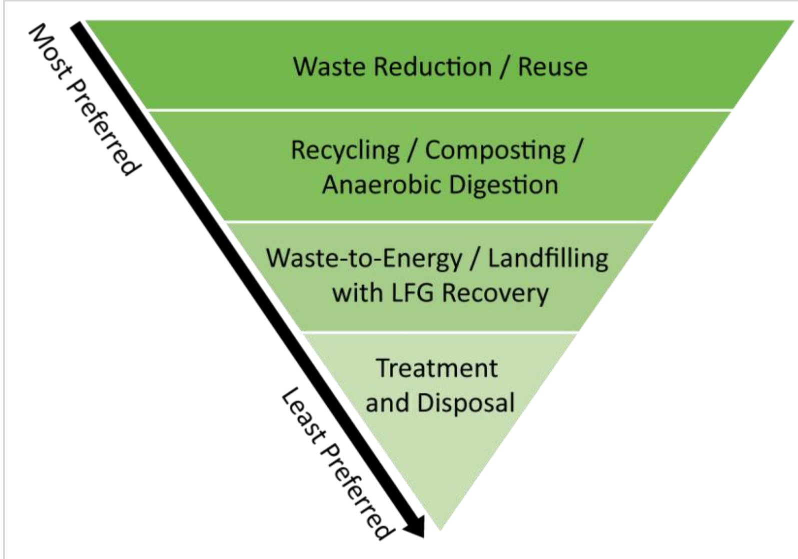

Figure 1-4. Preferred Components of Integrated Solid Waste Management

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

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

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

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

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

[12] U.S. EPA. August 1995. *Decision-Makers' Guide to Solid Waste Management, Volume II*. EPA 530-R-95-023. http://www.epa.gov/wastes/nonhaz/municipal/dmg2/.
[13] International Solid Waste Association. 2009. *Waste and Climate Change: ISWA White Paper.*

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

Figure 1-5. Metal Sorting at Materials Recovery Facility

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

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

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

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

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

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

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

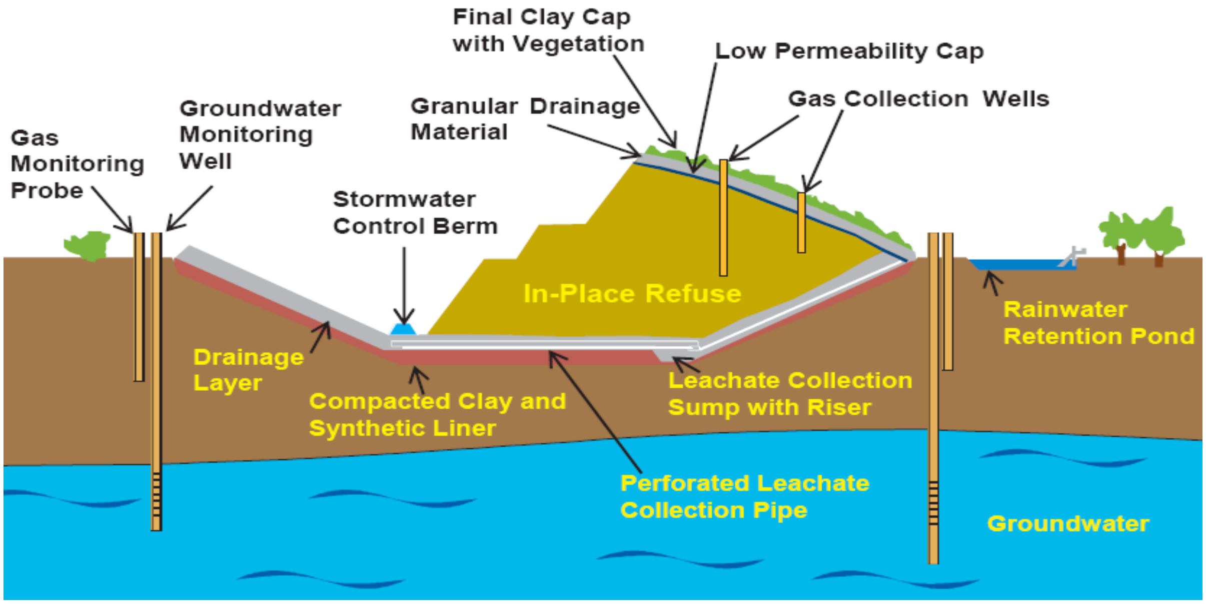

Figure 1-6. Modern Sanitary Landfill

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

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

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

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

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

Social Impacts of LFGE Project Development

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

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

Role of ISWM in Developing Sustainable Waste Management Practices

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

Example: Considerations for High Levels of Wet Organic Waste

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

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

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

Role of Landfill Gas Recovery and Use

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

Environmental, Social and Economic Benefits of LFG Recovery and Use

Collecting LFG for flaring, direct use or electricity generation provides environmental, social and economic benefits:

- Reduces greenhouse gas emissions
- Improves energy independence
- Produces cost savings
- Creates jobs
- Helps local economies

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

Best Practices for ISWM and LFGE Projects

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

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