LANDFILL GAS ENERGY: AN IMPORTANT COMPONENT OF INTEGRATED SOLID WASTE MANAGEMENT

Thomas A. Frankiewicz
U.S. EPA LMOP
Washington, DC

Chad A. Leatherwood, P.E.
SCS Engineers
Asheville, North Carolina

Brent L. Dieleman
SCS Engineers
Reston, Virginia

INTRODUCTION

Landfill gas energy (LFGE) is a critical component of an integrated approach to managing solid waste. With multiple environmental, social, and economic benefits, LFGE plays a critical role in the overall handling and management of municipal solid waste (MSW). In general, energy recovery within the solid waste sector plays a role in displacing fossil fuel use and reducing greenhouse gas (GHG) emissions. LFGE reduces GHG emissions and local air pollution, displaces fossil fuel use, and benefits the communities served by the landfill through economic development and job creation. Given these benefits, U.S. EPA has supported LFGE through programs like the Landfill Methane Outreach Program (LMOP) for more than fifteen years. LFGE projects:

- Destroy methane - a potent heat-trapping gas;
- Generate renewable energy and offset the use of non-renewable resources such as coal, natural gas, and oil;
- Provide cost–effective options for reducing methane emissions while generating energy;
- Reduce local air pollution;
- Create jobs, revenues, and cost savings.

BACKGROUND

LFGE is a small but important component of an integrated approach to solid waste management given that the use of landfills continues to remain the predominant method of waste disposal. The U.S. EPA waste hierarchy treats landfills and incineration equally, as environmentally acceptable disposal options for MSW. 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 the use of landfills is the available option, energy recovery improves the GHG profile and makes use of the energy generated when the organic fraction of MSW decomposes. Where landfills exist, the utilization of methane generated by the decomposing waste already in place to generate energy is the best-case option to reduce GHG emissions and provide an alternative to fossil fuel-based power generation.

This paper will highlight the environmental benefits of LFGE projects and showcase how landfills and energy recovery from landfill gas can be an essential component of a community's integrated solid waste management system. While environmental benefits of LFGE projects have long been clear, they are coming into question with respect to other strategies for waste management and the impact of LFGE projects in GHG emissions. Below are some key considerations in evaluating the benefits of LFGE.

KEY CONSIDERATIONS

- The U.S. EPA supports a waste management hierarchy and has set up several different programs to address this hierarchy (e.g. product stewardship, waste reduction, recycling, etc.) to move solid waste practices towards the top of the hierarchy.

- Currently, the predominant method for waste disposal in the U.S. is the use of sanitary landfills that meet strict U.S. EPA requirements.

- The solid waste industry is both a contributor and potential mitigator of GHG emissions.

- Energy recovery from landfill gas provides an opportunity to utilize the methane generated from existing landfills to reduce GHG emissions and offset fossil fuel use.

- LFGE does not compete with other solid waste disposal or diversion alternatives nor does it encourage additional landfilling. It is instead an important component of integrated solid waste management and preferable to landfilling without energy recovery and even more so to landfilling without gas capture and collection.

- The MSW management decisions a municipality makes are ultimately based on cost and demonstrated commercial application – all while meeting prevailing national, state, and local regulations.

INTEGRATED SOLID WASTE MANAGEMENT

The need to dispose of solid waste is a daily fact of life. Municipal managers know that a range of strategies and treatment processes must be employed to properly handle a waste stream – this is the heart of Integrated Solid Waste Management. Elements of an integrated solid waste management plan include: source reduction, recycling, composting, waste-to-energy (WTE), and landfills. Additionally, energy recovery from waste through combustion (WTE), LFGE, and the use of anaerobic digester biogas are demonstrated strategies for communities to recover value from the solid waste generated in their jurisdiction.

According to the U.S. EPA report titled, *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2009* (U.S. EPA 2010b), Americans generated 243 million tons of MSW. Of the waste generated, 132 millions tons (54.3 percent) were disposed of in MSW landfills. The remainder of the MSW stream was either recovered for recycling or composting (33.8 percent) or combusted in WTE facilities (11.9 percent).

Managing solid waste in the U.S. is a complex issue and requires a mix of technologies and processes that are highly dependant on a community's local conditions and economics. There is no one process or technology that is capable of managing all the MSW generated in the U.S. All available methods for managing solid waste must be used in the right proportion in a particular community in order to successfully manage the waste stream. Not only is this important from a cost perspective, but also because utilizing different methods will help maximize the reduction of GHG emissions. These different strategies for solid waste management are not in competition with each other. Rather, they are complimentary because they help a community manage its solid waste while meeting several critical obligations:

- Cost effective management of its waste;
- Minimization of environmental impacts;
- Maximization of material recovery;
- Maximization of energy benefit.

Energy from waste can be gained indirectly through energy conservation from recycling and directly from energy recovery through WTE, LFGE, and anaerobic digestion. However, only energy recovery will be discussed in this paper.

Local governments are under extreme scrutiny to minimize costs associated with public service, and whether they operate their own landfill or contract waste disposal to a private company, the cost of disposal is always a significant consideration. For example, according to the National Solid Wastes Management Association's *2005 Tip Fee Survey* (Repa 2005), the average cost per ton of MSW being routed to a landfill in 2004 was $34.29, whereas the average cost per ton of MSW being routed to a WTE facility was $61.64. Such a cost difference would most certainly be an issue from a local government perspective. Similarly, the costs associated with recycling and composting strategies are also considered as a local community determines its method for waste management.

The goal of LFGE projects is to promote beneficial utilization of landfill gas collected from waste that has already been disposed of in MSW landfills. It is possible to support the diversion of the organic fraction of discards from landfills so that uncontrolled methane is not generated and also support LFGE projects that utilize methane generated from organic waste already disposed in landfills. The two positions are not in conflict.

WASTE MANAGEMENT HIERARCHIES

The concept of a waste management hierarchy represents a group of waste management strategies, ordered based on the most preferred to the least preferred. While a graphical representation of a waste hierarchy is simple, the development and implementation of such strategies can be complex and involve a significant amount of planning, political will, economic resources, and community support.

The U.S. EPA established its waste management hierarchy for the purposes of prioritizing preferred methods of managing MSW in the U.S (Figure 1). The structure of EPA's waste management hierarchy is based on the environmental impact of waste management practices.

The most preferred method of waste management is to prevent the materials from entering the waste stream in the first place. There are several strategies for reducing solid waste, including material reuse along with design and manufacturing initiatives to produce products that last longer, use less materials, or both. Waste materials that are still produced should be recovered through recycling and composting programs. U.S. EPA has established a number of programs to increase the amount of MSW that is captured through recycling and composting, such as *WasteWise* and *Plug in e-Cycling* Programs.

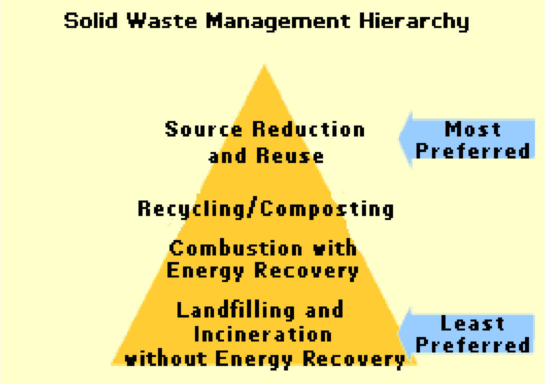

Figure 1: U.S. EPA Solid Waste Management Hierarchy (U.S. EPA 2011b)

MSW that is not diverted through recycling and composting programs are either disposed of in a landfill or through WTE. According to U.S. EPA's waste management hierarchy, there is currently no distinction made between landfills that incorporate an LFGE facility and those that do not.

Given that landfilling is still a predominant method of waste management in the U.S., other entities have proposed a waste hierarchy to reflect the renewable energy and GHG emission benefits associated with different types of solid waste management facilities. For example, Columbia University's Council for Sustainable Use of Resources (CU SUR) has developed a waste management hierarchy that elevates landfills with methane recovery or destruction systems over landfills where such systems are not in place. Additionally, landfills that not only capture methane gas but also utilize it for energy are further prioritized as more beneficial by elevating them up the hierarchy. Figure 2 showcases the waste management hierarchy developed by CU SUR.

Figure 2: CU SUR Waste Management Hierarchy (2010)

In recognizing the renewable energy generation and GHG reduction benefits in this hierarchy, LFGE and energy recovery have a greater role in moving solid waste practices up the hierarchy. In this respect, LFGE serves to elevate standard landfill practices to a more preferred role.

SOLID WASTE CONTRIBUTATION TO GHG EMISSIONS

EPA's 2011 report titled, *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2009* (U.S. EPA 2011a), identifies and quantifies the country's primary anthropogenic sources and sinks of GHG emissions. Figure 3 highlights that although methane remains a potent GHG that is over 20 times more effective at trapping heat than carbon dioxide, it makes up only 10.3 percent of the anthropogenic GHG emissions in the U.S.

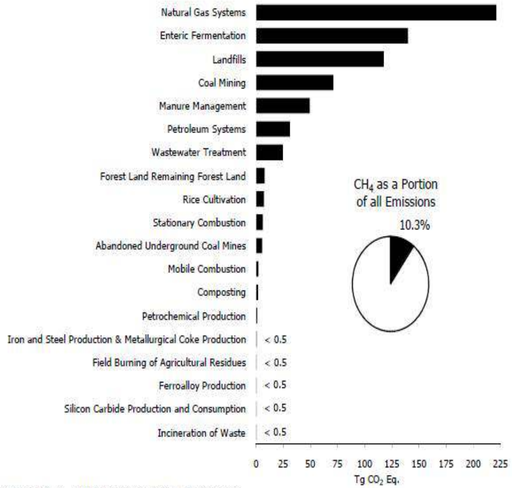

Figure ES-8: 2009 Sources of CH_4 Emissions

Figure 3: 2009 Sources of Methane Emissions

Of the anthropogenic sources of methane, landfills are ranked as the third largest contributor behind that of natural gas systems and enteric fermentation. This is a change in ranking from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008* report (U.S. EPA 2010a) where landfills were listed as the second largest source of methane emissions. Figure 4 from the draft 2011 GHG inventory report (U.S. EPA 2011a) further delineates the anthropogenic GHG emission sources and looks specifically at the waste sector. As the figure depicts, waste management activities – landfills, composting and wastewater treatment – account for 2.3 percent of the total anthropogenic GHG emissions. In 2009, methane emissions from landfills equaled nearly 118 $TgCO_2eq$ (U.S. EPA 2011a).

Carbon dioxide emissions from anthropogenic sources, such as energy generation, transportation and natural gas sources still account for the majority of GHG emissions each year (Figure 5, U.S. EPA 2011a).

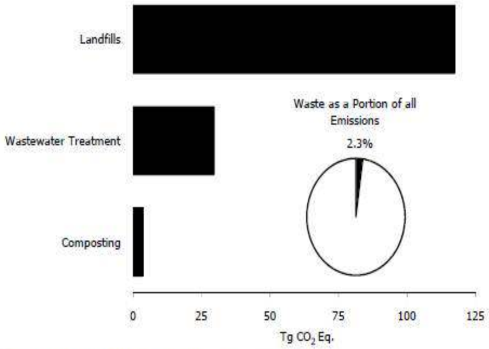

Figure 8-1: 2009 Waste Chapter Greenhouse Gas Sources

Figure 4: Methane Emissions from the Waste Sector (U.S. EPA 2011a)

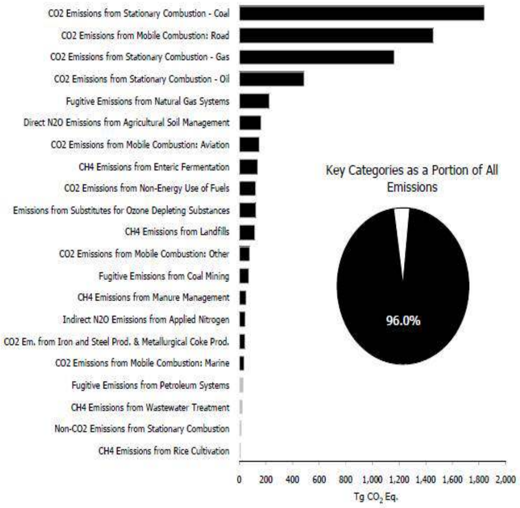

Figure ES-16: 2009 Key Categories

Notes: For a complete discussion of the key category analysis, see Annex 1.
Black bars indicate a Tier 1 level assessment key category.
Gray bars indicate a Tier 2 level assessment key category.

Figure 5: Methane Emissions from the Waste Sector (U.S. EPA 2011a)

ENERGY RECOVERY'S ROLE IN GHG MITIGATION

Energy recovery plays an important role within an integrated solid waste management strategy and also in moving solid waste management up the hierarchy to more preferred options. This is both because of the renewable energy and GHG reduction benefits. Below are the three main processes for direct energy recovery from solid waste.

Combustion with Energy Recovery

The U.S. EPA estimates that for every one ton of MSW processed through at WTE facility, approximately one ton of carbon dioxide equivalent emissions are avoided due to the following conditions (Michaels 2010):

- **Avoided Methane Emissions from Landfills** – MSW that is delivered to a WTE facility is not going to a landfill where it would otherwise decompose and generate methane, which is a GHG that is over 20 times more potent at trapping heat than carbon dioxide.

- **Avoided Carbon Dioxide Emissions from Fossil Fuel Combustion** – When a megawatt of electricity is generated from MSW, it displaces the need to generate that electricity from fossil fuel sources, and thus avoids the carbon dioxide emissions that would be generated.

- **Avoided Carbon Dioxide Emissions for Metals Recycling** – WTE facilities capture and recycle over 700,000 tons of metals annually. By recycling those metals, it avoids the carbon dioxide emissions that would have otherwise been generated by the mining of virgin materials and manufacturing of new metals.

Biogas from Anaerobic Digestion

Biogas recovery systems, sometimes known as anaerobic digesters, include the anaerobic digester, gas recovery, flare and/or generator set or boiler. During anaerobic digestion, bacteria break down manure in an oxygen-free environment. One of the natural products of anaerobic digestion is biogas, which typically contains between 60 to 70 percent methane, 30 to 40 percent carbon dioxide, and trace amounts of other gases.

When biogas is captured, it can be used to generate heat, hot water, or electricity - significantly reducing the cost of electricity and other farm fuels such as natural gas, propane, and fuel oil. Biogas can be flared to control odor if energy recovery is not feasible. Both the flaring and use of biogas reduce GHG emissions. Biogas is a renewable source of energy with much lower environmental impacts than conventional fossil fuel.

According to U.S. EPA AgSTAR's May 2010 report *Anaerobic Digesters Continue to Grow in the U.S. Livestock Market* (U.S. EPA AgSTAR 2010), farm digester systems alone produced an estimated 374 million kilowatt-hours (kWh) equivalent of useable energy. Besides generating electricity (323 million kWh), some operations use the gas as boiler fuel, upgrade it for injection into the natural gas pipeline, or flare it for odor control. Many of the projects that generate electricity also capture waste heat for various on-site thermal uses.

LFGE

The decomposition of organic wastes generates methane, a GHG and a primary component of landfill gas. The majority of landfills with LFGE projects are subject to Clean Air Act regulations (40 CFR 60 Subpart WWW) known as the New

Source Performance Standards (NSPS) and are required to install and operate a landfill gas collection and control system. According to the U.S. EPA-LMOP database, as of December 2010, there were approximately 505 landfills with LFGE projects in place. Of these sites, approximately 320 (63 percent) are subject to the collection and control requirements of the NSPS. For the approximately 185 landfills with LFGE projects in place that are not subject to the NSPS, the presence of an LFGE project represents the voluntary collection and control of LFG. This results in the reduction of emissions beyond what is required by EPA standards.

The benefits of LFGE in terms of GHG emission reductions are substantial. For example, a three megawatt LFGE facility requires approximately 1,075 standard cubic feet per minute (scfm) of LFG to operate. Not only does the combustion of this quantity of methane in an LFGE facility result in direct methane emission reductions, but also in indirect carbon dioxide equivalent emission reductions of about 14,300 metric tons per year, depending on the type of fuel that was used to generate the displaced electricity. The indirect environmental benefits of fossil fuel displacement through LFGE can amount to nearly 13 percent of the direct GHG emission reduction benefits from methane combustion.

The direct and indirect carbon dioxide equivalent emission reductions from a direct use project utilizing 1,000 standard cubic feet per minute (scfm) of LFG are 105,890 and 13,745 metric tonnes per year, respectively.

BENEFITS OF LFGE

LFGE reduces GHG emissions, local air pollution, displaces fossil fuel use, and benefits the communities the landfill serves, which is why U.S. EPA supports programs like LMOP. The list of benefits of LFGE is long, but generally they fall into the categories of environmental, energy, economic, and community.

Environmental

Environment is the cornerstone of LFGE benefits, given the local and global implications of capturing and utilizing landfill gas. There has already been much discussion of the GHG benefits of utilizing landfill gas, but there are others worth highlighting.

Landfill Gas Emission Reduction Benefits

Producing energy from landfill gas avoids the need to use non–renewable resources such as coal, oil, or natural gas to produce the same amount of energy. This can avoid gas end–user and power plant emissions of carbon dioxide and criteria pollutants such as sulfur dioxide (which is a major contributor to acid rain), particulate matter (a respiratory health concern), nitrogen oxides (NO_X - a contributor to smog), and trace hazardous air pollutants.

Note that - like all combustion devices - landfill gas electricity generation devices emit some NO_X, which can contribute to local ozone and smog formation (Figure 6). Depending on the fuels and technologies used by the power plant and the landfill project, the NO_X emission reductions from the power plant may not completely offset the NO_X emitted from the landfill gas electricity project. Overall, landfill gas electricity generation projects significantly improve the environment because of the large methane reductions, hazardous air pollutant reductions, and avoidance of the use of limited non–renewable resources such as coal and oil that are more polluting than landfill gas. There is also growing interest in converting landfill gas to transportation fuel. While there are still only a handful of projects in the U.S. where landfill gas is converted to compressed natural gas (CNG) or liquefied natural gas (LNG), a recent study by Argonne National Laboratory (Mintz et al, 2010) found many of the same benefits. Like power generation or direct use projects, landfill gas to CNG/LNG reduces GHG emissions, but it also displaces crude oil typically used in transportation fuel. Criteria pollutant reductions vary depending on where and how the LNG is produced.

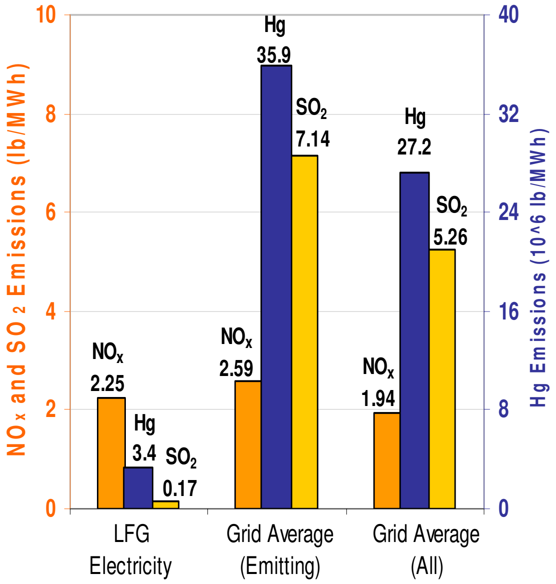

Figure 6: Comparison of Emission Reduction Benefits for Electricity Generation Using Landfill Gas (U.S. EPA 1998, U.S. EPA 2007)

Fugitive Emissions

The NSPS for MSW landfills requires that landfills above a specified size and emission level collect and control landfill gas emissions, measure emissions, and meet other operational standards. These landfills must install and operate a gas collection and control system per the design submitted to the appropriate air regulatory agency. Additionally, these landfills must conduct quarterly surface (fugitive) emission monitoring evaluations to determine if excessive amounts of fugitive organic gases are present. If a surface emission monitoring event shows elevated fugitive emissions, the landfill must adjust or modify their gas collection and control system to increase the amount of landfill gas recovered from the landfill and meet the surface emission criteria required by the landfill NSPS. These requirements are the same, regardless of whether methane is flared or an LFGE facility is present. Therefore, at landfills regulated by the NSPS, the presence of an LFGE project does not have an effect on the control of fugitive methane emissions.

However, landfills with LFGE projects are more likely to employ greater efforts to maximize collection efficiencies than landfills which only flare the gas to meet NSPS emissions requirements. Given the level of capital investment for an LFGE project, it is inherently in the project developer's interest to collect and utilize as much landfill gas as possible to make the project financially successful. Thus, a landfill with an LFGE facility, if subject to the NSPS rule, will likely have the same or lower amounts of fugitive emissions than a landfill that is simply flaring the gas.

Energy

Landfill gas is considered a renewable resource and therefore qualifies as renewable energy. Currently thirty-six states plus the District of Columbia and Puerto Rico have implemented Renewable Portfolio Standard or Renewable Portfolio Goal programs where landfill gas may be an eligible renewable resource.

LMOP estimates that about 505 landfills across the U.S. capture the methane gas and use it to produce 1,684 MW of power and supply 305 million metric standard cubic feet of gas per day for direct use. The collection and utilization of methane from these landfills plus the avoided GHG emissions from conventional electricity sources is equivalent to preventing more than 96 million metric tons of carbon dioxide equivalent emissions per year. LMOP has also identified 510 candidate landfills – landfills that may have the potential to support a landfill gas renewable energy project.

Economic

In addition to environmental benefits, LFGE projects have significant economic benefits. The benefits range from job creation during the construction and operation of the project to providing a cost savings to facilities that convert to landfill gas as a fuel source, and in some cases LFGE projects have attracted new businesses all together. Below are some calculations of "average" jobs created as well as examples of cost savings and new facilities built because of ability to use landfill gas.

Typical Project Job Creation

LFGE projects have a substantial impact on economic growth and jobs creation. A typical three megawatt landfill gas electricity project is estimated to have the following economic and job creation benefits during the construction year:

- Add more than $1.5 million in new project expenditures for the purchase of equipment.
- Directly create at least five jobs for the construction and installation of the equipment.
- Considering the ripple effect, will increase the statewide economic output by $4.3 million and employ 20-26 people.

Oftentimes, facilities will invest in LFGE projects because of the significant cost savings and long-term energy price stability these projects provide. LFGE is also a way to meet corporate sustainability goals. Below are a few examples of the savings achieved:

- Kimberly-Clark reports saving $800,000 per year by utilizing landfill gas in boilers at its Beech Island, South Carolina paper products manufacturing facility.
- SC Johnson estimates $1 million in net savings per year at its plant in Racine, Wisconsin.

In other cases, LFGE has been used as an engine to create new job growth. In Indiana, the Newton County Business Energy Park was created to attract new industry to an area that had lost several key industries in previous years. It currently generates enough energy to entirely support the first tenant in a newly developed business park intended to be fueled solely by renewable energy. Urban Forest Recyclers, a manufacturer of wholesale egg cartons, uses LFG in the drying process. As the business park grows, energy from the landfill is expected to support the energy needs of the entire park.

Community

Landfills are a community responsibility and landfill gas is increasingly seen as a community resource. LFGE projects involve citizens, nonprofit organizations, local governments, and industry in sustainable community planning. These projects go hand–in–hand with community and corporate commitments to cleaner air, renewable energy, economic development, improved public welfare and safety, and reductions in GHG emissions. By linking communities with innovative ways to deal with their landfill gas, LFGE projects contribute to the creation of livable communities that enjoy increased environmental protection, better waste management, and responsible community planning.

CONCLUSION

LFGE – and energy recovery in general - is an important component of an integrated approach to solid waste management. While there are multiple considerations for developing an integrated solid waste management plan, LFGE can help move the handling of waste further up the waste management hierarchy, creating renewable energy and reducing GHG emissions.

REFERENCES

Michaels, T., 2010, "The 2010 ERC Directory of Waste-to-Energy Plants," accessed from http://www.wte.org/userfiles/file/ERC_2010_Directory.pdf.

Mintz, M., Han, J., Wang, M., Saricks, C., 2010, "Well-to-Wheels Analysis of Landfill Gas-Based Pathways and Their Addition to the GREET Model," Center for Transportation Research Energy Systems Division, Argonne National Laboratory.

Repa, E.W., 2005, "NSWMA's 2005 Tip Fee Survey," accessed from http://www.environmentalistseveryday.org/docs/Tipping-Fee-Bulletin-2005.pdf.

Sullivan, P., and EEC Research Associate, 2010 "The Importance of Landfill Gas Capture and Utilization in the U.S." Columbia University Earth Engineering Center, Council for the Sustainable Use of Resources.

U.S. Environmental Protection Agency AgSTAR, 2010, "Anaerobic Digesters Continue to Grow in the U.S. Livestock Market," accessed from www.epa.gov/agstar/documents/2010_digester_update.pdf.

U.S. Environmental Protection Agency, 2011a, "Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2009," accessed from http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

U.S. Environmental Protection Agency, 2007, "eGRID," accessed from www.epa.gov/cleanenergy/energy-resources/egrid/index.

U.S. Environmental Protection Agency, 1998, "Emission Factors & AP 42, Compilation of Air Pollutant Emission Factors," accessed from www.epa.gov/ttnchie1/ap42/.

U.S. Environmental Protection Agency, 2010a, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008," accessed from http://www.epa.gov/climatechange/emissions/usgginv_archive.html.

U.S. Environmental Protection Agency, 2010b, "Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2009," accessed from http://www.epa.gov/osw/nonhaz/municipal/msw99.htm.

U.S. Environmental Protection Agency, 2011b, "Solid Waste Management Hierarchy," accessed from http://www.epa.gov/wastes/nonhaz/municipal/hierarchy.htm.