Landfill Gas Energy Cost Model

LFGcost-Web

U.S. Environmental Protection Agency
Landfill Methane Outreach Program (LMOP)

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CONTINUE

LANDFILL METHANE OUTREACH PROGRAM

User's Manual

Landfill Methane Outreach Program (LMOP)
U.S. Environmental Protection Agency
Washington, DC

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Introduction

The Landfill Gas Energy Cost Model, LFGcost-Web, is a software tool developed for EPA's Landfill Methane Outreach Program (LMOP) to conduct <u>initial</u> economic analyses of prospective landfill gas (LFG) energy recovery projects in the United States. **Analyses performed using LFGcost-Web are considered preliminary and should be used for guidance only.** **A detailed final feasibility assessment should be conducted by qualified LFG professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from an LFG energy project.**

The software was created in Microsoft® Excel to make the computations transparent and to facilitate its updating as the economics of LFG energy projects mature. This document describes how to use the LFGcost-Web spreadsheet tool and presents the technical basis underlying the software methodology.

The various LFG energy project types that can be analyzed in LFGcost-Web include:

- New LFG collection and flaring systems (not expansion of existing systems);
- Direct LFG utilization projects (direct-use);
- Boiler retrofit projects;
- Processing LFG into a high Btu gas;
- Processing LFG into an alternative vehicle fuel (CNG);
- Leachate evaporators;
- Electricity generation with standard turbines;
- Electricity generation with standard reciprocating engines;
- Electricity generation with microturbines;
- Electricity generation with small reciprocating engines;
- Electricity generation and hot water production with combined heat and power (CHP) reciprocating engines;
- Electricity generation and steam production with CHP turbines; and
- Electricity generation and hot water production with CHP microturbines.

LFGcost-Web is an LFG energy project cost estimating tool developed for EPA's LMOP. LFGcost-Web estimates LFG generation rates using a first-order decay equation. This equation is used to estimate generation potential but cannot be considered an absolute predictor of the rate of LFG generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The default inputs and costs estimated by LFGcost-Web are based on typical project designs and for typical landfill situations. **The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost-Web.**

Using LFGcost-Web

Summary of Revisions

LFGcost-Web, Version 3.0, replaces Version 2.2. Significant revisions between Version 2.2 and Version 3.0 of LFGcost-Web include:

▸ Updated cost equations for collection and flaring systems, direct-use projects, and standard engine projects.

▸ Added project type of onsite CNG production and fueling station.

▸ Updated default user inputs.

▸ Edited model structure to allow users to view equations and calculations previously hidden and to enter optional user inputs previously locked.

▸ Made model and user's manual available to all stakeholders on LMOP's website.

General Instructions and Guidelines

The first worksheet within LFGcost-Web (see INST worksheet) provides important instructions on the proper use of LFGcost-Web. These instructions include the size ranges over which LFGcost-Web is expected to be most accurate for a given project type. Within these size ranges LFGcost-Web is estimated to have an accuracy of ± 30 to 50 percent. Using LFGcost-Web to evaluate projects outside of these recommended ranges will likely provide cost estimates with a greater uncertainty. The INST worksheet also provides definitions of input and output parameters, outlines the organization of LFGcost-Web, and summarizes important notes described below regarding the model and its functionality.

Detailed information about running the model for unique project scenarios is contained in Appendices C, D, and E. Appendix C provides guidance for evaluating projects with multiple equipment and/or start dates, Appendix D outlines the suggested inputs for local government-owned projects, and Appendix E explains how to set up and interpret results for boiler retrofit projects.

Inputs

The second worksheet of LFGcost-Web (see INP-OUT worksheet) is where users enter the required input data for evaluating an LFG energy project. In this worksheet, the ***Required User Inputs*** table allows users to enter the minimum input parameters required for conducting an economic analysis. The ***Optional User Inputs*** table gives users the option to adjust the default input parameters used by LFGcost-Web. If these optional input parameters are not known for the project being evaluated, the default parameters should provide a reasonable economic evaluation of the project.

Outputs

The INP-OUT worksheet summarizes the results of the economic and environmental analysis performed by LFGcost-Web in the ***Outputs*** table. This table has been arranged so users of LFGcost-Web are able to change the project design and immediately see the resulting change in economic analysis, without having to switch to another worksheet in LFGcost-Web. Most users of LFGcost-Web will not need to look at other worksheets in LFGcost-Web when conducting a routine economic analysis.

Calculators

LFGcost-Web provides two calculators to assist model users. The ***Waste Acceptance Rate Calculator***, in the WASTE worksheet, calculates the average annual waste acceptance rate based on the amount of waste-in-place and the year representing the time required to accumulate this waste. Model users who do not know the average annual waste acceptance rate for a particular landfill can use this calculator to estimate this rate.

The ***Financial Goals Calculator***, located below the ***Outputs*** table of the INP-OUT worksheet, calculates the initial product price that would be required for the project to achieve its financial goals. It is assumed that financial goals are achieved when the internal rate of return (IRR) equals the discount rate and the net present value is equal to $0. If a given economic analysis does not achieve its financial goals or greatly exceeds the goals, model users can use this calculator to determine the initial product price that is required to pay back the investment within the lifetime of the project.

Model users **must** select "Enable Macros" when prompted (immediately after opening the file) to allow the LFGcost-Web software to use the embedded macros that control the operation of the ***Financial Goals Calculator***. Enabling macros is discussed further in the "Software Requirements" section below. The ***Financial Goals Calculator*** can be used **ONLY** when the ***Solver Add-in*** has been installed and loaded within Microsoft® Excel. Please see the on-screen instructions below the calculator button to load the ***Solver Add-in***.

Summary Reports

The first summary report (see REPORT worksheet) presents input, output, and curve information similar to data found in the INP-OUT and CURVE worksheets. The printout will be labeled with the landfill name or identifier that has been entered at the top of the INP-OUT worksheet as well as the file name and current date. The appropriate initial product price needed to achieve financial goals **must** be determined for each LFG energy project scenario using the ***Financial Goals Calculator*** in order for the correct financial goal prices to appear in the report.

The second summary report (see RPT-CASHFLOW worksheet) presents a detailed summary of the project cash flow analysis using data similar to data found in the ECN worksheet. Given the detailed nature of this spreadsheet, it may be appropriate to include only for certain scenarios.

An Adobe Portable Document Format (PDF) of the summary reports can be created from the REPORT and/or RPT-CASHFLOW worksheets in order to save or distribute read-only electronic copies. In order to create a PDF of the reports users must have a printer driver installed on their computer that has the capability to convert files to this format (for example, PDF995 or Adobe Acrobat). With this PDF printer driver installed, users can follow the steps listed below to create a PDF of the summary reports.

1. Select the worksheet tab(s) you are interested in printing.

2. Select *Print* from the menu.

3. Select the PDF printer driver (e.g., PDF995) from the *Printer* drop-down menu and click OK.

4. Once the PDF dialog box appears in a new window, users can preview the report and save it to a file location of their choice. If using Adobe Acrobat, users can also specify which worksheets to include in the .pdf file.

5. More information about downloading and purchasing PDF printer drivers can be obtained at http://www.pdf995.com/ or http://www.adobe.com.

Software Requirements

LFGcost-Web has been specified as a "Read Only" file. The "Read Only" restriction is intended to protect the original file from being accidentally over-written by users. This restriction can be removed by changing the file properties via Windows Explorer or file management applications. However, instead of removing these restrictions, we recommend users save a copy of LFGcost-Web under a new file name when running each economic analysis. **When saving LFGcost-Web, users must *Save As* an "Excel 97-2003 Workbook (*.xls)" to maintain all the functionality of the model.**

The LFGcost-Web model was created in Microsoft® Excel and must be operated in a Microsoft® Excel 2000, 2002 (XP), 2003, 2007, 2010, or 2013 environment. Earlier versions of Microsoft® Excel are not able to properly run the model due to embedded macros. Several functions operate slowly when running LFGcost-Web on computers that have a processor speed of 333 MHz or less.

Model users must "Enable Macros" when prompted (immediately after opening the file) to allow the LFGcost-Web software to use the embedded macros.

Microsoft® Excel 2000, 2002 (XP), and 2003 users must set their *Macro Security Level* to "Medium" (menu select *Tools…Macro… Security… Security Level*) prior to opening LFGcost-Web to allow the "Enable Macros" option to be selected. Microsoft® Excel 2007, 2010, and 2013 users must set their *Macro Security Level* to "Disable all macros with notification" (menu select *Developer…Macro Security*). [If the *Developer* menu is not displayed in Excel 2007, click the *Microsoft Office Button*, select *Excel Options*, and then in the *Popular* category, under *Top options for working with Excel*, select *Show Developer tab in the Ribbon*. If the *Developer* menu is not displayed in Excel 2010 or 2013, on the *File* menu, select *Options*, and then in the *Customize Ribbon* category, under *Customize the Ribbon*, check the *Developer* box.] Then, upon opening LFGcost-Web, users must select "Enable this content" from the *Security Warning – Options…* box that appears beneath the menu.

Cost Basis

The costs and economic parameters, such as net present value (NPV), are based on actual or "nominal" rates and include the effects of inflation. For example, if a project was constructed in 2013 and began operation in 2014, then installed capital costs in the year of construction are in 2013 dollars, operating costs for the initial year of operation are in 2014 dollars, and NPV at year of construction is in 2013 dollars. Within the structure of the various cost estimating worksheets in LFGcost-Web, the costs for any given year in the life of the project are presented in that specific year's dollars.

Cost Scope

The cost estimates produced by LFGcost-Web include all direct and indirect costs associated with the project. In addition to the direct costs for equipment and installation, LFGcost-Web includes indirect costs associated with:

‣   Engineering, design, and administration;

‣   Site surveys and preparation;

‣   Permits, right-of-ways, and fees; and

▶ Mobilization/demobilization of construction equipment.

Since these costs are estimated for an average project site in the United States, individual sites will experience variations to these costs due to unique site conditions.

Cost Uncertainty

The uncertainty in the cost estimates produced by LFGcost-Web is estimated to be $\pm$ 30 to 50 percent. As detailed in the list below, this uncertainty is a composite of uncertainties related to LFG generation rates, future economic conditions, and unique site characteristics. LFGcost-Web allows users to enter a *Cost uncertainty factor* in the **Optional User Inputs** table that adjusts the economic outputs to test the sensitivity of the proposed project economics to potential project uncertainties. The *Cost uncertainty factor* is discussed further in the "INP-OUT: Inputs/Outputs" section below.

The uncertainty of $\pm$ 30 to 50 percent is estimated based on the following:

▶ Equipment used in the actual LFG energy project may need to be purchased at a larger size than what is estimated by LFGcost-Web, because the standard equipment sizes vary from one manufacturer to another. This may result in an underestimate of the actual costs.

▶ Unusual site conditions may limit the type of LFG energy project that could be selected or require additional site preparation and equipment. This may result in an underestimate of the actual costs.

▶ Environmental or permitting constraints may lead to higher costs. This can vary from additional air pollution controls to increased equipment maintenance. This may result in an underestimate of the actual costs.

▶ Regional construction cost differences within the United States may result in either an overestimate or an underestimate of the actual costs, depending on the region where the landfill is located.

Further Assistance

If you would like assistance using LFGcost-Web, please contact LMOP at www.epa.gov/lmop/contact.html.

Analyses performed using LFGcost-Web are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified LFG professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from an LFG energy project.

Technical Basis of LFGcost-Web

Table 1 lists the worksheets that comprise the LFGcost-Web spreadsheet model. The following sections document the design and technical basis of the contents of these worksheets.

Table 1. Worksheet Names and Functions in LFGcost-Web

Worksheet Name	Function
INST	General instructions and guidelines
INP-OUT	Required and optional user inputs and model output results
WASTE	Optional user inputs for annual waste acceptance data
REPORT	Summary report of user inputs, model outputs, and curve
RPT-CASHFLOW	Detailed summary of 15-year cash flow analysis
CURVE	Landfill gas generation, collection, and utilization curve
ENV	Environmental benefits calculations
FLOW	Landfill gas generation, collection, and utilization calculations
C&F	Design and costing of new collection and flaring system
DIR	Design and costing of direct-use of landfill gas
BLR	Design and costing of boiler retrofit
HBTU	Design and costing of high Btu processing plant
CNG	Design and costing of onsite CNG production and fueling station
LCH	Design and costing of leachate evaporator
TUR	Design and costing of standard turbine-generator set
ENG	Design and costing of standard reciprocating engine-generator set
MTUR	Design and costing of microturbine-generator set
SENG	Design and costing of small reciprocating engine-generator set
CHPE	Design and costing of CHP reciprocating engine-generator set
CHPT	Design and costing of CHP turbine-generator set
CHPM	Design and costing of CHP microturbine-generator set
ECN	Economic analysis (cash flow) calculations

INST: General Instructions and Guidelines

▸ Glossary of Input and Output Parameters – The definitions contained within these two tables in the model are provided in the "INP-OUT: Inputs/Outputs" section below.

▸ LFG Energy Project Types and Recommended Sizes – This table outlines the 12 LFG energy project types included in LFGcost-Web, as shown in Table 2 below. In addition, project sizes are recommended for each type of LFG energy project, with units varying by project type as follows:

 – Direct-use, boiler retrofit, high Btu, and CNG projects - cubic feet per minute (ft^3/min) of LFG.

 – Leachate evaporater projects - gallons of leachate evaporated per day.

 – Projects generating electricity (engines, turbines, and microturbines) - amount of electricity generated in kilowatts (kW) or megawatts (MW).

LFGcost-Web is designed to accommodate the recommended size ranges given for each type of LFG energy project. Model output results may not be valid for project sizes outside of the recommended project size ranges.

▸ Workbook Design – This table summarizes the name and function for each of the 22 worksheets contained in LFGcost-Web, as shown in Table 1 above.

▸ Important Notes – The items listed under ***Important Notes*** in the model are described in more detail in the "Using LFGcost-Web" section above.

Table 2. LFG Energy Project Types and Recommended Sizes

LFG Energy Project Type	Recommended Project Size
Direct-use (Boiler, Greenhouse, etc.)	400 to 3,000 ft^3/min LFG
Boiler Retrofit	Less than or equal to 3,000 ft^3/min LFG
High Btu Processing Plant	1,000 to 10,000 ft^3/min LFG
Onsite CNG Production and Fueling Station	50 to 600 ft^3/min LFG
Leachate Evaporators	5,000 gallons leachate per day and greater
Standard Turbine-Generator Sets	Greater than 3 MW
Standard Reciprocating Engine-Generator Sets	800 kW and greater
Microturbine-Generator Sets	30 to 750 kW
Small Reciprocating Engine-Generator Sets	100 kW to 1 MW
CHP Reciprocating Engine-Generator Sets	800 kW and greater
CHP Turbine-Generator Sets	Greater than 3 MW
CHP Microturbine-Generator Sets	30 to 300 kW

INP-OUT: Inputs / Outputs

▸ Required User Inputs – These inputs **MUST** be entered in order to properly characterize the landfill and project parameters. Defaults are not provided for the required inputs because they are unique for each landfill and project.

– **Year landfill opened** – Four-digit year that the landfill opened or is planning to open.
– **Year of landfill closure** – Four-digit year that the landfill closed or is expected to close.
– **Area of LFG wellfield to supply project** – Acreage of the landfill that contains waste and generates LFG to be collected and utilized by the LFG energy project. The model assumes one well per acre to determine vertical gas well, wellhead, pipe gathering system, and other costs for the collection and flaring system. Acreage should represent area of landfill for gas collection to feed project, not total landfill area. Gas collection and flaring cost estimates represent a complete new system (costs for expansion of an existing system will be higher); inaccurate cost estimates may result for smaller landfill areas (<10 acres) due to economic infeasibility of designing and installing an entire new collection and flaring system.
– **Method for entering waste acceptance data** – Choose one of the three methods listed to represent average or actual tonnage of municipal solid waste (MSW) accepted each year the landfill is open.
  - Average annual waste acceptance rate – Average annual tons of MSW accepted each year the landfill is open. This method should be used if actual yearly waste acceptance data are unknown.
  - Waste acceptance rate calculator – see "WASTE: Waste Calculator/Disposal History" section below.
  - Annual waste disposal history – see "WASTE: Waste Calculator/Disposal History" section below.
– **LFG energy project type** – Pick list to choose one of the 12 LFG energy project types you want to analyze. Table 2 (above) contains a list of project types to use for selecting the project type appropriate for the size of your project.
– **Will LFG energy project cost include collection and flaring costs?** – Determines if costs for new vertical well collection and flaring equipment (not expansion of existing equipment) are included in the total LFG energy project cost.
  - Select Y (for yes) if the landfill does NOT have collection and flaring equipment installed and you want to include collection and flaring costs in the total project cost.
  - Select N (for no) if the landfill already contains a collection and flaring system or you do not want to include collection and flaring costs in the total project cost.
  Collection and flaring costs cannot be included if boiler retrofit costs are not combined with direct-use project costs.
– **For Leachate Evaporator projects: Amount of leachate collected** – Gallons of landfill leachate that is collected and treated annually.
– **For Boiler Retrofits: Will boiler retrofit costs be combined with direct-use project costs?** – Determines if direct-use project costs are included in the total LFG energy project cost.
  - Select Y (for yes) if boiler retrofit costs are to be combined with other direct-use project costs (i.e., developer incurs all costs).
  - Select N (for no) if boiler retrofit costs are kept separate (i.e., end user incurs boiler retrofit costs only).
  This input is discussed in further detail in Appendix E (Evaluating Boiler Retrofit Projects). Collection and flaring costs cannot be included if N is entered or input cell is left blank.
– **For Boiler Retrofits: Distance between end user's property boundary and boiler** – Number of miles between the end user's property boundary and the boiler.

INP-OUT: Inputs / Outputs

Required User Inputs (continued)

– **For Direct-use, High Btu, and CHP projects: Distance between landfill and end use, pipeline, or CHP unit**
- For direct-use projects, the number of miles between the landfill and the end user of the LFG. When costs are combined for direct-use and boiler retrofit projects, this input is the distance from the landfill to the end user's property boundary.
- For high Btu projects, the number of miles between the landfill and the natural gas pipeline or the end user of the high Btu gas.
- For CHP projects, the number of miles between the landfill and the CHP engine, turbine, or microturbine.

   To maintain integrity of the cost estimates, this distance should be limited to 10 miles or less.

– **For CHP projects: Distance between CHP unit and hot water/steam user** – Number of miles between the CHP engine, turbine, or microturbine and the end user of the hot water/steam. To maintain integrity of the cost estimates, this distance should be limited to 1 mile or less. The CHP unit and the hot water/steam user are typically co-located, which would be a distance of zero (0) miles.

– **Year LFG energy project begins operation** – Four-digit year that the LFG energy project installation will be complete and begin operating.

▸ Optional User Inputs – These inputs are initially set to the suggested defaults provided. To edit the optional inputs, enter the requested input in the *Optional User Input Data* column. (Note: Data in the *Suggested Default Data* column are protected and cannot be edited.)

– **LFG energy project size** – Pick list to choose LFG flow rate over the project life used to design the LFG energy project – Minimum, Average, Maximum, or Defined by user. When 'Defined by user' is selected, an LFG design flow rate MUST be entered in the input box below the LFG energy project size selection. The default is for minimum LFG generation. However, the optimum project size will vary for different project types. You are encouraged to try multiple size options to determine the optimum size for your project conditions.
- For direct-use projects, the optimum size is often based on the maximum gas flow.
- The optimum size for electricity generation projects (including CHP) is often based on the average flow.

– **For user-defined project size only: Design flow rate** – The design LFG flow rate, in cubic feet per minute, entered for projects sized manually by users. 'Defined by user' MUST be selected for LFG energy project size to indicate the project size is user-defined.

– **Methane generation rate constant, k** – The methane generation constant (k) used to determine the amount of LFG generated generally varies depending on the climate of the area surrounding the landfill. There are three k values to choose from: 0.04 per year for areas that receive 25 inches or more of rain annually; 0.02 per year for drier (arid) areas that receive less than 25 inches of rain annually; or 0.1 per year for bioreactors. The suggested default is 0.04 per year for typical climates. The k value entered should equal one of these suggested values unless site-specific data are available. k values are discussed further in the "FLOW: Landfill Gas Flow Rate Calculations" section below.

– **Potential methane generation capacity of waste, L_O** – The potential methane generation capacity of the waste (L_O) in cubic feet per ton. This parameter primarily depends on the type of waste in the landfill. The default of 3,204 cubic feet per ton should be used to represent MSW unless site-specific data are available. L_O values are discussed further in the "FLOW: Landfill Gas Flow Rate Calculations" section below.

– **Methane content of landfill gas** – The methane content of LFG generally ranges between 45 and 60 percent. This parameter is used to calculate environmental benefits and normalize LFG production. The default of 50 percent should be used unless site-specific data are available.

INP-OUT: Inputs / Outputs

Optional User Inputs (continued)

- **Average depth of landfill waste** – The average depth of the landfill waste (in feet) is used to estimate costs of the vertical gas wells for the new collection and flaring system (not expansion of existing system). The suggested default is 65 feet, but this should be changed if site-specific average waste depth is known for the landfill.
- **Landfill gas collection efficiency** – The equipment used to collect LFG normally operates at efficiencies between 70 and 95 percent. The suggested default is 85 percent.
- **Utilization of CHP hot water/steam potential** – For CHP projects, the percent of hot water/steam used by the end user, out of the potential hot water/steam generated by the CHP unit. The range for the utilization is between 0 and 100 percent. The suggested default is 100 percent.
- **Expected LFG energy project lifetime** – Estimated number of years that the LFG energy project will be operating. The default project lifetime is 15 years, but the model sets the lifetime to 10 years for microturbines (non-CHP applications). The project lifetime for all other project types should be greater than or equal to 10 years, but cannot exceed 15 years.

  Generally, 15 years is considered the average lifetime for the equipment installed in LFG energy projects and thus, the longest period over which to evaluate project economics. In addition, LFGcost-Web uses the project lifetime for determining the tax-based capital depreciation rate. In Section 179 of the 2001 Federal Tax Code, the IRS recommends using 15 years for the depreciation of electricity and fuel pipeline projects that are analogous to LFG energy projects. For these reasons, the default project lifetime is 15 years and it is recommended not to use a value of less than 10 years or more than 15 years. However, microturbine projects (non-CHP applications) should be set to a project lifetime of 10 years to match their expected life of 10 years, as observed by manufacturers of LFG microturbines.

- **Operating schedule** – For all projects except leachate evaporators, the LFG may be used seasonally (e.g., for space heating six months out of the year). This parameter allows users to specify how many hours of the day, days of the week, and weeks of the year the project will be requiring LFG. The suggested defaults are 24 hours per day, 7 days per week, and 52.14 weeks per year to result in the maximum operating schedule of 8,760 hours per year.
- **Global warming potential (GWP) of methane** – Pick list to choose 21 or 25 for GWP of methane, which is used for environmental benefits and direct methane reductions for greenhouse gas reduction credits. The suggested default is 25 to reflect the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).
- **Will cost of metering station that serves as custody transfer point be borne by end user?** – For boiler retrofit projects, determines if the cost to install a metering station will be incurred by the end user because it will serve as a custody transfer point.
  - Select Y (for yes) if metering station costs will be included.
  - Select N (for no) if metering station costs will not be included.
  The suggested default is Y, to include metering station costs.
- **Loan lifetime** – The period over which the project loan will be repaid. The loan lifetime is assumed to begin during the year of project design and construction. It is common for project loan periods to be limited to half or two-thirds of the equipment lifetime to assure that the loan is repaid before the project ends. Since much of the equipment used in LFG energy projects has a projected lifetime of 15 years, the default loan lifetime is set to 10 years. However, loan lifetime should not exceed the project lifetime, because it is not practical to assume that project financing would exceed the expected life of the project equipment and revenues. See Appendix A for additional information.
- **Interest rate** – The actual or "nominal" interest rate of the project loan. The suggested default is 6 percent based on recent Moody Corporate AAA and BAA bond rates published by the Federal Reserve. See Appendix A for additional information.

INP-OUT: Inputs / Outputs

Optional User Inputs (continued)

- **General inflation rate** – The inflation rate applied to operation and maintenance (O&M) costs. The suggested default is 2.5 percent based on recent Consumer Price Indexes. See Appendix A for additional information.

- **Equipment inflation rate** – The inflation rate applied to project equipment (capital) costs. The suggested default is 2 percent based on recent plant construction cost indices. See Appendix A for additional information.

- **Marginal tax rate** – The tax rate used to estimate tax payments; this item is not applicable to projects funded and developed by local governments. For publicly owned projects, see Appendix D (Evaluating Local Government-Owned Projects). The suggested default tax rate is 35 percent for projects funded and developed by private entities, which is based on recent LFG energy project experience with commercial projects. See Appendix A for additional information.

- **Discount rate** – The discount rate, or hurdle rate, is used to determine the present value of future cash flows. This rate represents the internal time-value of money (on an actual or "nominal" basis) used by companies to evaluate projects. The suggested default is 8 percent based on recent LFG energy project experience with commercial projects. See Appendix A for additional information.

- **Down payment** – The down payment on the project loan. The suggested default is 20 percent based on recent LFG energy project experience with commercial projects. See Appendix A for additional information.

- **Energy tax credits** – Energy tax credits may be available for LFG utilization projects in select areas. These energy tax credits include LFG or high Btu utilization ($/million Btu) and electricity generation ($/kWh). Municipalities installing LFG energy projects are generally tax exempt and are not directly eligible for tax credits. In these instances, the values for the tax credits should be entered as zero. However, a municipality may arrange to sell the tax credits to a third party. In this situation, only the third-party payment to the municipality, provided in return for the tax credit, should be entered as energy tax credits in LFGcost-Web. All of the default values are initialized to zero.

- **Direct credits** – Other credits can be evaluated for special situations. All of the default values are initialized to zero.

  - *Greenhouse gas reduction credit ($/MTCO_2E)* – for direct methane reductions from the landfill and avoided carbon dioxide generated from displacing fossil fuels (in units of $ per metric ton of carbon dioxide equivalents). Direct methane reductions (i.e., methane collected and either flared or utilized in an LFG energy project) may contribute to this credit if the landfill is not required to collect and combust LFG (e.g., complying with the NSPS/EG). You have the option of including (Y for yes) or excluding (N for No) direct methane reductions. The suggested default is Y, to include direct methane reductions.

  - *Renewable electricity credit ($/kWh)* – represents tradable renewable certificates (TRCs) or "green tags" that are created when a renewable energy facility generates electricity (in units of $ per kilowatt-hour). Each unique certificate represents all of the environmental benefits of a specific quantity of renewable electricity generation, namely the benefits received when fossil fuels are displaced.

  - *Renewable fuel credit ($/gallon)* – for alternative vehicle fuel (CNG) projects, including projects with Renewable Identification Numbers (RINs) where a gallon of renewable fuel produced in or imported into the United States receives a credit.

  - *Avoided leachate disposal ($/gallon)* – for leachate disposal costs previously incurred for leachate evaporator projects.

  - *Construction grant ($)* – a government cash grant for project capital costs.

INP-OUT: Inputs / Outputs

Optional User Inputs (continued)

- **Royalty payment for landfill gas utilization** – Project developers that do not own the LFG may be required to pay the landfill owner a royalty for the amount of gas utilized (in units of $ per million Btu). The default is initialized to zero.
- **Cost uncertainty factor** – This parameter can be used to adjust the capital and annual costs by a specified percentage to determine the impact of cost uncertainty on the project economics. A positive value would increase all capital and operating costs by the specified percentage, and a negative value would decrease the costs by the specified percentage. The suggested default is zero (0) percent, and the suggested values for establishing a cost range for a typical project are 20% and -20%. For further discussion about uncertainties, see the "Using LFGcost-Web: Cost Uncertainty" section above.
- **Initial year product price** – Initial year product prices are suggested for the sale of energy from the project. These prices represent the initial year of project operation. See Appendix A for additional information and documentation of the review of current product prices used to determine the following suggested default prices:
    - Landfill gas production – $1.75/million Btu
    - Electricity generation – $0.06/kWh
    - CHP hot water/steam production – $4.50/million Btu
    - High Btu gas production – $2.75/million Btu
    - CNG production – $2.00/gasoline gallon equivalent (GGE) [to determine $/diesel gallon equivalent (DGE), divide $/GGE by 0.866]
- **Annual product price escalation rate** – The initial year product price will be escalated by this annual value in the future years of the project. The suggested default is 1 percent, as discussed in Appendix A.
- **Electricity purchase price for projects NOT generating electricity** – The price for electricity purchased by projects that do not generate their own electricity, such as direct-use projects. The suggested default is $0.085 per kWh, as discussed in Appendix A.
- **Annual electricity purchase price escalation rate** – The annual escalation rate applied to purchased electricity. The suggested default is 1 percent, as discussed in Appendix A.

▸ Outputs – Results of the economic analysis and environmental benefits. Economic outputs are discussed further in the "ECN: Economic Analysis" section below.

Economic Analysis (Individual project costs can vary by ±30-50% due to situational factors. Adjust the cost uncertainty factor in the *Optional User Inputs* table to test the impact of cost uncertainty on project economics.):

- **Design project size** – For all projects except leachate evaporators, the amount of LFG (in cubic feet per minute) used to determine the design flow rate of the project.
- **Generating capacity for projects generating electricity** – For electricity generation projects, the generation capacity (in kilowatts) of the power producing equipment.
- **Average project size for projects NOT generating electricity** – For direct-use, boiler retrofit, high Btu, CNG, and leachate evaporator projects, average project size represents the average amount of actual LFG utilized over the lifetime of the LFG energy project. This output is presented in units of million cubic feet per year and cubic feet per minute.
- **Average project size for projects generating electricity** – For engine, turbine, microturbine, and CHP projects, average project size represents average annual kilowatt-hours of electricity generated (net).
- **Average project size for CHP projects producing hot water/steam** – For CHP projects, average project size represents the average annual amount of hot water/steam produced in units of million Btu per year.

INP-OUT: Inputs / Outputs

Outputs: Economic Analysis (continued)

- **Total installed capital cost for year of construction** – Total capital cost of the installed LFG energy project.
- **Annual costs for initial year of operation** – Equipment operating and maintenance (O&M) cost for the initial year of the LFG energy project.
- **Internal rate of return** – Return on investment based on the total revenue from the project and construction grants, minus down payment (i.e., cash flow). More simply, the rate that balances the overall costs of the project with the revenue earned over the lifetime of the project such that the net present value of the investment is equal to zero.
- **Net present value at year of construction** – First year monetary value that is equivalent to the various cash flows, based on the discount rate. In other words, the difference between the costs and revenue over the lifetime of the project calculated at the present time based on a selected discount rate.
- **Net present value payback (years after operation begins)** – Years required for the total present value to exceed zero. An output of "None" means there is no return on investment or no payback in the LFG energy project lifetime.

Environmental Benefits:

- **Total lifetime amount of methane collected and destroyed** – Total million cubic feet of methane that is collected and either destroyed by the flare (assuming 100 percent destruction efficiency) or utilized by the LFG energy project.
- **Average annual amount of methane collected and destroyed** – Average annual million cubic feet of methane that is collected and either destroyed by the flare (assuming 100 percent destruction efficiency) or utilized by the LFG energy project on a yearly basis.
- **GHG value of total lifetime amount of methane utilized in energy project*** – Total million metric tons of methane (represented by carbon dioxide equivalents, or MMTCO$_2$E) that is utilized by the LFG energy project. This output takes into account the operating schedule and gross capacity factor of the project. Flared gas is not included in this value.
- **GHG value of average annual amount of methane utilized in energy project*** – Average annual million metric tons of methane (represented by carbon dioxide equivalents per year, or MMTCO$_2$E per year) that is utilized by the LFG energy project on a yearly basis. This output takes into account the operating schedule and gross capacity factor of the project. Flared gas is not included in this value.
- **Total lifetime carbon dioxide from avoided energy generation*** – Total emissions that are avoided because LFG is utilized instead of combusting fossil fuels. This output is presented in units of million metric tons of carbon dioxide equivalents. For direct-use, boiler retrofit, and high Btu projects, LFG is assumed to offset the combustion of natural gas. For CNG projects, LFG is assumed to offset the combustion of diesel fuel. For projects that generate electricity (turbines, engines, and microturbines), electricity produced is assumed to offset the collective combustion of fossil fuels in U.S. power plants.
- **Average annual carbon dioxide from avoided energy generation*** – Average annual emissions that are avoided because LFG is utilized instead of combusting fossil fuels. This output is presented in units of million metric tons of carbon dioxide equivalents per year. For direct-use, boiler retrofit, and high Btu projects, LFG is assumed to offset the combustion of natural gas. For CNG projects, LFG is assumed to offset the combustion of diesel fuel. For projects that generate electricity (turbines, engines, and microturbines), electricity produced is assumed to offset the collective combustion of fossil fuels in U.S. power plants.

*Note: These output values are presented in scientific notation. This format is used because these outputs are smaller values, typically less than 0.1. An output value of 1.23E-02 is equivalent to 1.23 x 10^{-2} or 0.0123.

WASTE: Waste Calculator / Disposal History

▶ <u>Waste Acceptance Rate Calculator</u> – calculates the average annual waste acceptance rate in tons per year based upon the amount of waste-in-place and the year representing the time required to accumulate this amount of MSW. This calculator is meant to be used when average or year-to-year annual acceptance rates are unknown.

    – **Waste-in-place –** total tons of MSW accepted and placed in the landfill.
    – **Year representing waste-in-place** – four-digit year that corresponds to the waste-in-place tonnage.

<div align="center">

- OR -

</div>

▶ <u>Annual Waste Disposal History</u> – this table allows users to enter yearly waste acceptance rate data in tons per year for up to 75 years. The waste disposal history should be used **only** when year-to-year waste acceptance is known for each year that the landfill operates. In other words, the annual waste acceptance column **must** be completed for all years beginning with the landfill open year and ending with the landfill closure year. The *Year* and *Waste-In-Place* columns within the table are protected and cannot be edited.

    – **Year** – four-digit year with Year 0 being the open year of the landfill.
    – **Annual waste acceptance** – tons of MSW accepted per year for the corresponding year.
    – **Waste-in-place** – a cumulative total of the tonnage of MSW accepted for previous years.

CURVE: Landfill Gas Curve

▸ The graph presented on the CURVE worksheet displays the LFG generation, collection, and utilization in average standard cubic feet per minute from the year the project begins operations to 25 years beyond start-up.

– The LFG generation curve is represented by a thick solid line and shows the estimated amount of gas that the landfill is capable of producing. The gas generation does not take into account the fact that not all of the gas is recoverable.

– The LFG collection curve is represented by a thin solid line and provides an estimate for the amount of gas collected. The gas collection rate is estimated by multiplying the gas generation rate by the collection efficiency. For more information about collection efficiency, please see the "INP-OUT: Inputs/Outputs" section above.

– The LFG utilization curve is shown as a dashed line and represents the amount of gas utilized by the project for the years the project is operating. Collection efficiency, project size, operating schedule, gross capacity factor, and parasitic loss efficiency are taken into account when calculating the LFG utilization. An example of the LFG generation, collection, and utilization curve is shown in Figure 2 for a 15-year project beginning operation in 2015.
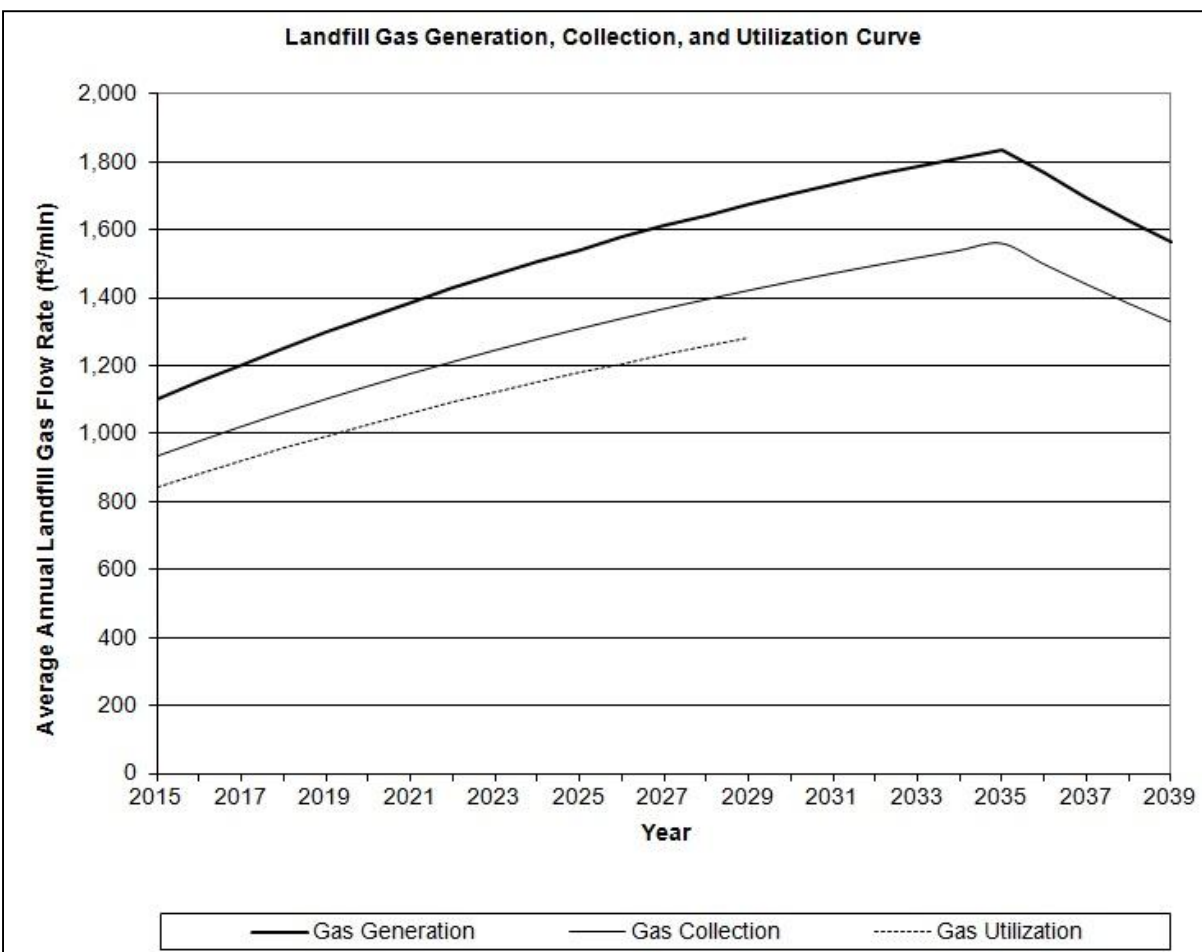

Figure 1. Example of LFG generation, collection, and utilization curve in LFGcost-Web

ENV: Environmental Benefits

▸ Environmental benefits are determined for each year of the LFG energy project. The benefits are calculated separately for projects that DO NOT generate electricity and projects that DO generate electricity. The four primary calculations that occur for each type of project are listed below:

 – **Methane collected and destroyed** – total annual amount of methane (in cubic feet per year, ft^3/yr) that is collected and either destroyed by the flare or utilized by the LFG energy project.

$$\begin{pmatrix} Methane\ collected \\ and\ destroyed \\ (ft^3/yr) \end{pmatrix} = \begin{pmatrix} Annual\ gas \\ collection \\ (ft^3/yr) \end{pmatrix} * \begin{pmatrix} \%\ methane \\ in\ LFG \end{pmatrix}$$

 – **Direct methane reduced** – total annual amount of methane (in million metric tons carbon dioxide equivalents per year, $MMTCO_2E/yr$) that is collected and either destroyed by the flare or utilized by the LFG energy project.

$$\begin{pmatrix} Direct\ methane \\ reduced \\ (MMTCO_2E/yr) \end{pmatrix} = \begin{pmatrix} Methane\ collected \\ and\ destroyed \\ (ft^3/yr) \end{pmatrix} * \left(\frac{0.0423\ lbs\ methane}{ft^3\ methane} \right) * \left(\frac{short\ ton}{2,000\ lbs} \right)$$
$$* \left(\frac{0.9072\ MT}{short\ ton} \right) * \left(\frac{GWP\ of}{methane} \right) * \left(\frac{MMT}{10^6\ MT} \right)$$

 – **Methane utilized by project** – annual million metric tons of methane (in $MMTCO_2E/yr$) that is utilized by the LFG energy project.

$$\begin{pmatrix} Methane\ utilized \\ (MMTCO_2E/yr) \end{pmatrix} = \begin{pmatrix} Actual\ gas \\ utilization \\ (ft^3/yr) \end{pmatrix} * \begin{pmatrix} \%\ methane \\ in\ LFG \end{pmatrix} * \left(\frac{0.0423\ lbs\ methane}{ft^3\ methane} \right) * \left(\frac{short\ ton}{2,000\ lbs} \right)$$
$$* \left(\frac{0.9072\ MT}{short\ ton} \right) * \left(\frac{GWP\ of}{methane} \right) * \left(\frac{MMT}{10^6\ MT} \right)$$

ENV: Environmental Benefits

Environmental Benefits (continued)

– **Avoided carbon dioxide emissions** – annual carbon dioxide emissions avoided because LFG is utilized instead of combusting fossil fuels (MMTCO$_2$E/yr). Avoided carbon dioxide emissions are not estimated for leachate evaporator projects.

- For direct-use, boiler retrofit, and high Btu projects, carbon dioxide emissions typically offset the combustion of natural gas. The emission factor of 0.12037 pounds carbon dioxide per cubic foot natural gas is referenced in Appendix H of "Instructions for Form EIA-1605, Voluntary Reporting of GHGs" (Nov. 2010), http://www.eia.gov/survey/form/eia_1605/instructions.pdf.

- For CNG projects, carbon dioxide emissions typically offset the combustion of diesel fuel. The emission factor of 161 pounds carbon dioxide per million Btu is referenced.

- For projects that generate electricity (turbines, engines, and microturbines, including CHP), carbon dioxide emissions offset the combustion of fossil fuels at U.S. power plants. The emission factor of 1.18 pounds carbon dioxide per kilowatt-hour represents the estimated average 2014 U.S. power emissions. CHP avoided carbon dioxide emissions are determined using the same natural gas emission factor as direct-use projects, as described above.

Direct-use and boiler retrofit projects:

$$\begin{pmatrix} Direct\text{-}use\,avoided \\ carbon\,dioxide \\ emissions \\ (MMTCO_2E/yr) \end{pmatrix} = \begin{pmatrix} Actual\,gas \\ utilization \\ (ft^3/yr) \end{pmatrix} * \begin{pmatrix} \%\,CH_4 \\ in\,LFG \end{pmatrix} * \begin{pmatrix} \dfrac{1,012\,Btu}{ft^3\,methane} \end{pmatrix} * \begin{pmatrix} \dfrac{ft^3\,natural\,gas}{1,050\,Btu} \end{pmatrix}$$

$$* \begin{pmatrix} \dfrac{0.12037\,lbs\,CO_2}{ft^3\,natural\,gas} \end{pmatrix} * \begin{pmatrix} \dfrac{short\,ton}{2,000\,lbs} \end{pmatrix} * \begin{pmatrix} \dfrac{0.9072\,MT}{short\,ton} \end{pmatrix} * \begin{pmatrix} \dfrac{MMT}{10^6\,MT} \end{pmatrix}$$

High Btu projects:

$$\begin{pmatrix} HighBtu\,avoided \\ carbon\,dioxide \\ emissions \\ (MMTCO_2E/yr) \end{pmatrix} = \begin{pmatrix} Actual\,gas \\ utilization \\ (ft^3/yr) \end{pmatrix} * \begin{pmatrix} \%\,CH_4 \\ in\,LFG \end{pmatrix} * \begin{pmatrix} \dfrac{90\%\,Conversion\,Efficiency\,LFG\,CH_4}{High\,Btu\,CH_4} \end{pmatrix} * \begin{pmatrix} \dfrac{1,012\,Btu}{ft^3\,methane} \end{pmatrix}$$

$$* \begin{pmatrix} \dfrac{ft^3\,natural\,gas}{1,050\,Btu} \end{pmatrix} * \begin{pmatrix} \dfrac{0.12037\,lbs\,CO_2}{ft^3\,natural\,gas} \end{pmatrix} * \begin{pmatrix} \dfrac{short\,ton}{2,000\,lbs} \end{pmatrix} * \begin{pmatrix} \dfrac{0.9072\,MT}{short\,ton} \end{pmatrix} * \begin{pmatrix} \dfrac{MMT}{10^6\,MT} \end{pmatrix}$$

ENV: Environmental Benefits

Environmental Benefits (continued)

    <u>CNG projects:</u>

$$\begin{pmatrix} CNG \; avoided \\ carbon \; dioxide \\ emissions \\ (MMTCO_2 E / yr) \end{pmatrix} = \begin{pmatrix} Actual \; gas \\ utilizatio \, n \\ (ft^3 / yr) \end{pmatrix} * \begin{pmatrix} \% \; CH_4 \\ in \; LFG \end{pmatrix} * \left(\frac{70\% \; Conversion \, Efficiency \; LFG \, CH_4}{CNG \, CH_4} \right) \left(\frac{1,012 \, Btu}{ft^3 \; methane} \right)$$

$$* \left(\frac{161 \, lbs \; CO_2}{million \, Btu} \right) * \left(\frac{million \, Btu}{10^6 \, Btu} \right) * \left(\frac{short \, ton}{2,000 \, lbs} \right) * \left(\frac{0.9072 \, MT}{short \, ton} \right) * \left(\frac{MMT}{10^{12} \, MT} \right)$$

    <u>Non-CHP electricity generation projects:</u>

$$\begin{pmatrix} Electricit \, y \; generation \\ avoided \; carbon \\ dioxide \; emissions \\ (MMTCO_2 E / yr) \end{pmatrix} = \left(\frac{1.18 \, lbs \; CO_2}{kWh} \right) * \begin{pmatrix} Net \; electricit \, y \\ produced \\ (kWh / yr) \end{pmatrix} * \left(\frac{short \, ton}{2,000 \, lbs} \right)$$

$$* \left(\frac{0.9072 \, MT}{short \, ton} \right) * \left(\frac{MMT}{10^6 \, MT} \right)$$

    <u>CHP electricity generation projects:</u>

$$\begin{pmatrix} CHP \\ avoided \; carbon \\ dioxide \; emissions \\ (MMTCO_2 E / yr) \end{pmatrix} = \begin{pmatrix} \left(\frac{1.18 \, lbs \; CO_2}{kWh} \right) * \begin{pmatrix} Net \; electricit \, y \\ produced \\ (kWh / yr) \end{pmatrix} * \left(\frac{short \, ton}{2,000 \, lbs} \right) \\ * \left(\frac{0.9072 \, MT}{short \, ton} \right) * \left(\frac{MMT}{10^6 \, MT} \right) \end{pmatrix} +$$

$$\begin{pmatrix} \begin{pmatrix} Hot \; water/steam \; produced \\ (million \; Btu/yr) \end{pmatrix} * \left(\frac{0.12037 \, lbs \; CO_2}{ft^3 \, (natural \; gas)} \right) * \left(\frac{short \, ton}{2,000 lbs} \right) \left(\frac{0.9072 \, MT}{short \, ton} \right) * \left(\frac{MMT}{10^6 \, MT} \right) * \\ \left(\frac{1}{0.80 (efficiency \; of \; hot \; water/steam \; boiler)} \right) * \left(\frac{ft^3 natural \; gas}{1,050 Btu} \right) * \left(\frac{10^6 \; Btu}{million \; Btu} \right) \end{pmatrix}$$

FLOW: Landfill Gas Flow Rate Calculations

▸ The first-order decay equation is commonly used to estimate LFG generation from MSW landfills. LFG production is normalized for actual methane content entered in the ***Optional User Inputs*** of the INP-OUT worksheet. The LFG generation equations used in LFGcost-Web vary slightly depending on the type of waste acceptance rate data used (see the "INP-OUT: Inputs/Outputs" section above). The two first-order decay equations used in LFGcost-Web to determine LFG generation are as follows:

First-Order Decay Equation for Average Annual Waste Acceptance Rate:

$$Q_t = (1/(CH_4/100)) * L_o * R * [e^{(-kc)} - e^{(-kt)}]$$

Where,
   Q_t =   landfill gas generation rate at time t (ft^3/year)
   CH_4 =   methane content of landfill gas (%)
   L_o =   potential methane generation capacity of waste (ft^3/ton)
   R   =   average annual waste acceptance rate during active life (tons)
   k   =   methane generation rate constant (1/year)
   c   =   time since landfill closure (years)
   t   =   time since the initial waste placement (years)

First-Order Decay Equation for Waste Disposal History (year-to-year acceptance rate):

$$Q_t = \Sigma_i [(1/(CH_4/100)) * k * L_o * M_i * e^{(-kti)}]$$

Where,
   Q_t =   landfill gas generation rate at time t (ft^3/year)
   CH_4 =   methane content of landfill gas (%)
   k   =   methane generation rate constant (1/year)
   L_o =   potential methane generation capacity of waste (ft^3/ton)
   M_i =   waste acceptance rate in the ith section (tons)
   t_i =   age of the ith section (years)

▸ The suggested default potential methane generation capacity (L_o) is 3,204 cubic feet per ton (100 cubic meters per megagram). This default L_o value comes from EPA's "Compilation of Air Pollutant Emission Factors", commonly known as "AP-42", and is appropriate for most landfills. Estimation of L_o is generally treated as a function of the moisture and organic content of the waste. Therefore, it is recommended that users utilize L_o values that differ from these defaults only when site-specific data are available to reasonably estimate the potential methane generation capacity for a particular landfill.

FLOW: Landfill Gas Flow Rate Calculations

Landfill Gas Flow Rate Calculations (continued)

▸ Estimation of the methane generation rate constant (k) is a function of a variety of factors, including moisture, pH, temperature, and landfill operating conditions. The constant k can vary from less than 0.02 per year to more than 0.285 per year, depending on these site-specific factors. EPA's AP-42 recommends that areas receiving 25 inches or more of rain per year use a default k of 0.04 per year, and drier (arid) areas receiving less than 25 inches of rain per year use a default k of 0.02 per year. A default k value of 0.1 per year is commonly accepted for bioreactors or wet landfills (yet values >0.1 per year are common). It is recommended that users utilize k values that differ from these defaults only when site-specific data are available to reasonably estimate the methane generation constant for a particular landfill.

▸ LFG flow rates are determined for each year of the LFG energy project. The eight primary calculations that occur are listed below:

  – **Annual gas generation** – cubic feet of LFG generated per year.
  – **Gas generation flow rate –** cubic feet of LFG generated per minute.
  – **Annual gas collection** – cubic feet of LFG collected per year.
  – **Gas collection flow rate** – cubic feet of LFG collected per minute.
  – **Annual project gas utilization** – cubic feet of LFG per year available for use by the LFG energy project, which depends on the project size chosen. This calculation does not account for operating schedule, gross capacity factor, or parasitic loss efficiency.
  – **Project gas utilization flow rate** – cubic feet of LFG per minute available for use by the LFG energy project, which depends on the project size chosen. This calculation does not account for take operating schedule, gross capacity factor, or parasitic loss efficiency.
  – **Annual actual gas utilization** – actual cubic feet of LFG utilized per year by the LFG energy project. Based on user input and the type of project chosen, this calculation accounts for project size, operating schedule, gross capacity factor, and parasitic loss efficiency.
  – **Actual gas utilization flow rate** – actual cubic feet of LFG utilized per minute by the LFG energy project, on an average annual basis. Based on user input and the type of project chosen, this calculation accounts for project size, operating schedule, gross capacity factor, and parasitic loss efficiency.

C&F: Collection and Flaring System	
Typical components include	▸ Engineering, permitting, and administration; ▸ Wells and wellheads; ▸ Pipe gathering system (includes additional fittings/installations); ▸ Condensate knockout system; ▸ Blowers; ▸ Instrument controls; ▸ Flare; and ▸ Site survey, preparation, and utilities.
Drilling and pipe crew mobilization	$20,000
Installed capital cost of vertical gas extraction wells	$$\left(\frac{\text{average waste}}{\text{depth (ft)}} - 10\,\text{ft} \right) * \$85/\text{ft} = \$X/\text{well},$$ ($4,675 * number of wells) for default average waste depth of 65 feet
Installed capital cost of wellheads and pipe gathering system	$17,000 * number of wells
Installed capital cost of knockout, blower, and flare system	$(\text{ft}^3/\text{min})^{0.61} * \$4,600$
Engineering, permitting, and surveying	$700 * number of wells
Annual O&M cost (excluding energy costs)	($2,600 * number of wells) + $5,100 for flare
Electricity usage by blowers	$0.002 \text{ kWh} / \text{ft}^3$

Note: Raw cost data are in 2013$'s.

DIR: Direct-Use System	
Typical components include	- Engineering, permitting, and administration; - Skid-mounted filter, compressor, and dehydration unit; - Pipeline to convey gas to project (includes below-grade HDPE piping, condensate removal system, and pipe fittings); and - Site survey, preparation, and utilities. (Cost does not include payments for right-of-way easements which may or may not be required.)
Installed capital cost of skid-mounted filter, compressor, and dehydration unit	($360 * ft^3/min) + $830,000
Installed capital cost of pipeline	*For flow rates ≤1,000 ft^3/min (8" piping):* ($80* feet of pipeline) + $178,000 *For flow rates 1,001 - 3,000 ft^3/min (12" piping):* ($106 * feet of pipeline) + $207,000
Annual O&M cost (excluding electricity)	$\$57,000 * \left(\dfrac{\text{ft}^3/\text{min}}{700} \right)^{0.2}$
Electricity usage	*For pipeline distances of 5 miles or less:* 0.002 kWh/ft^3 *For pipeline distances where* $\left(\dfrac{miles * (ft^3/\min)^2}{10^6} \right) > 120:$ 0.003 kWh/ft^3
Gross capacity factor[*]	Assume 90%

Note: Raw cost data are in 2013$'s.

[*]   Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

BLR: Boiler Retrofit	
Typical components include	▸ Pipeline delivery from end user's property boundary to boiler (includes below-grade HDPE piping, condensate removal system and pipe fittings, engineering, permitting, and administration); ▸ Metering station (includes LFG analyzer and flow meter and moisture analyzer); and ▸ Boiler conversion for seamless controls (includes fuel delivery system, burner modifications, and control modifications). Raw cost data for boiler conversion provided by CPL Systems, Inc.
Installed capital cost of pipeline delivery from end user's property boundary to boiler	*For flow rates ≤1,000 ft³/min (8" piping):* $75 * (feet of pipeline) + $88,000 *For flow rates 1,001 - 3,000 ft³/min (12" piping):* $100 * (feet of pipeline) + $105,500
Installed capital cost of metering station	*For flow rates ≤1,000 ft³/min:* $79,000 *For flow rates 1,001 - 3,000 ft³/min:* $89,000
Installed capital cost of boiler conversion for seamless controls[*]	($113 * ft³/min) + $84,143
Gross capacity factor[**]	Assume 90%

Raw cost data are in 2010$'s.

[*] Boiler conversion costs for manual controls are significantly less than seamless controls, but it is becoming increasingly common for boiler owners with manual controls to upgrade to seamless controls due to increased optimization. Conversion costs for multi-burner boilers, typically located at petrochemical plants & refineries, are significantly higher than seamless controls due to inherent complexities at facilities where these types of boilers are often found. Cost does NOT include boiler re-certification, which may be necessary due to state/local regulations or insurance requirements.

[**] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

HBTU: High Btu Processing Plant	
Typical components include	▸ Compressor; ▸ Gas separators; ▸ Gas dryers; ▸ Pipeline to convey gas to project site or natural gas pipeline; and ▸ Site work, building construction, utilities, and total facility engineering, design, and permitting. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost of compressor, gas separators, and dryers for pipeline quality gas	$$\left(\frac{\text{ft}^3/\text{min}}{2{,}000}\right)^{0.63} * \$8{,}400{,}000$$
Installed capital cost of pipeline	$330,000 * miles of pipeline
Annual O&M cost (excluding electricity)	$$0.22 * \left(\frac{\text{ft}^3 / yr}{1{,}000}\right)$$
Electricity usage	0.009 kWh/ft^3
High Btu production	[(1,012 Btu/ft^3 CH$_4$) * (% CH$_4$ in LFG) * (90% conversion efficiency) * (million Btu/10^6 Btu)] = 0.0005 million Btu/ft^3 LFG with default 50% CH$_4$ in LFG
Gross capacity factor[*]	Assume 93%

Note: Raw cost data are in 2008$'s.

[*] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

CNG: Onsite CNG Production and Fueling Station	
Typical components include	▶ LFG-to-CNG conversion and conditioning unit; ▶ Fueling station equipment (includes compressors, dispensers, and storage tanks for all fill types -- fast, slow, combo fast/slow); ▶ Winterization equipment, if needed (includes heat tracing and insulation of hydrogen sulfide vessel and heated and insulated structure over other equipment); ▶ Engineering and project management (includes site design, layout, and permitting); and ▶ Installation of all equipment, startup, and training. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost	$95,000 * (ft^3/min)$^{0.6}$
Annual O&M cost for media and equipment replacement and parasitic load	$1.00/gasoline gallon equivalent (GGE)[*]
CNG production	[(1,012 Btu/ft^3 CH$_4$) * (% CH$_4$ in LFG) * (65% conversion efficiency)] / 111,200 Btu/GGE = 0.0030 GGE/ft^3 LFG with default 50% CH$_4$ in LFG
Gross capacity factor[**]	Assume 93%

Note: Raw cost data are in 2013$'s.

[*] To determine $/diesel gallon equivalent (DGE), divide $/GGE by 0.866.

[**] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, and weather related interruptions of the local utilities.

LCH: Leachate Evaporator	
Typical components include	▶ Leachate evaporation unit; ▶ Leachate surge tank; ▶ Process control instruments; and ▶ Site work, housings, utilities, and total facility engineering, design, and permitting.
Annualized capital and O&M costs[*]	$\$320,000 * \left(\dfrac{\text{gallons evaporated/yr}}{3,467,500} \right)^{0.19}$
Fuel use rate	80 Btu/gallon evaporated
Electricity usage	0.055 kWh/gallon evaporated
Leachate evaporation limit	No more than 95% of the available leachate can be evaporated

Note: Raw cost data are in 2008$'s.

[*] Competitive rental costs were found for leachate evaporation, and were used to develop a combined capital and operating cost.

TUR: Standard Turbine-Generator Set	
Typical components include	▶ Gas compression and treatment (includes dehydration equipment, siloxane adsorbers, and filtration); ▶ Turbine and generator (includes exhaust silencers and all wiring and plumbing); ▶ Electrical interconnect equipment; and ▶ Site work, housings, utilities, and total facility engineering, design, and permitting. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost	*For most situations:* $[(\$2,340 * \text{kW capacity}) - (0.103 * (\text{kW capacity})^2)]$ + \$250,000 for interconnect *For [\$2,340 – (0.103 * kW capacity)] < 1,015:* $(\$1,015 * \text{kW capacity}) + \$250,000$ for interconnect
Annual O&M cost (excluding energy)	\$0.0144 * kWh generated/yr (before parasitic uses)
Parasitic loss efficiency	88% of capacity due to parasitic electrical needs of compression and treatment
Fuel use rate	13,000 Btu/kWh generated (HHV) (before parasitic uses)
Gross capacity factor[*]	Assume 93%

Note: Raw cost data are in 2008$'s.

[*] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

ENG: Standard Reciprocating Engine-Generator Set	
Typical components include	▶ Gas compression and treatment (includes dehydration equipment and filtration); ▶ Reciprocating engine and generator (includes motor controls, switch-gear, radiators, exhaust silencers, and all wiring and plumbing); ▶ Electrical interconnect equipment; and ▶ Site work, housings, utilities, and total facility engineering, design, and permitting. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost	[($1,300 * kW capacity) + $1,100,000] + $250,000 for interconnect
Annual O&M cost (excluding energy)	$0.025 * kWh generated/yr (before parasitic uses)
Parasitic loss efficiency	93% of capacity due to parasitic electrical needs of compression and treatment
Fuel use rate	11,250 Btu/kWh generated (HHV) (before parasitic uses)
Gross capacity factor[*]	Assume 93%

Note: Raw cost data are in 2013$'s.

[*] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

MTUR: Microturbine–Generator Set	
Typical components include	▸ Gas compression and treatment (includes dehydration equipment, siloxane adsorbers, and filtration); ▸ Microturbine and generator (includes exhaust silencers and all wiring and plumbing); ▸ Electrical interconnect equipment; and ▸ Site work, housings, utilities, and total facility engineering, design, and permitting. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost	$19,278 * (kW capacity)$^{0.6207}$
Annual O&M cost (excluding energy)	($0.0736 – (0.0094 * ln(kW capacity))) * kWh generated/yr (before parasitic uses), includes gas cleanup system O&M and microturbine overhauls
Parasitic loss efficiency	83% of rated capacity due to parasitic electrical needs of boost compressor and cooling water pumps, fans, and dryer system
Fuel use rate	14,000 Btu/kWh generated (HHV) (before parasitic uses)
Gross capacity factor[*]	Assume 93%

Note: Raw cost data are in 2006$'s.

[*] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

SENG: Small Reciprocating Engine–Generator Set	
Typical components include	▶ Gas compression and treatment (includes dehydration equipment and filtration); ▶ Reciprocating engine and generator (includes motor controls, switch-gear, radiators, exhaust silencers, and all wiring and plumbing; ▶ Electrical interconnect equipment; and ▶ Site work, housings, utilities, and total facility engineering, design, and permitting. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost	$2,300 * kW capacity
Annual O&M cost (excluding energy)	$0.024 * kWh generated/yr (before parasitic uses)
Parasitic loss efficiency	92% of capacity due to parasitic electrical needs of compression and treatment
Fuel use rate	36 ft^3/kWh generated (before parasitic uses)
Gross capacity factor[*]	Assume 93%

Note: Raw cost data are in 2008$'s.

[*] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

CHPE: CHP Reciprocating Engine-Generator Set	
Typical components include	▸ Gas compression and treatment (includes dehydration equipment and filtration); ▸ Heat recovery exchangers; ▸ Reciprocating engine and generator (includes motor controls, switch-gear, radiators, exhaust silencers, and all wiring and plumbing); ▸ Electrical interconnect equipment; ▸ Site work, housings, utilities, and total facility engineering, design, and permitting; ▸ Gas pipeline from compressor to engine; ▸ Water pipelines from engine to hot water user (assumes 2 lines for supply and return); and ▸ Circulation pump for water pipelines. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost	($1,900 * kW capacity) + ($250,000 for interconnect) + ($63 * ft of gas pipeline) + ($106 * ft of trench for water pipelines) + ($12,000 for circulation pump)
Annual O&M cost (excluding energy)	$0.02 * kWh generated/yr (parasitic)
Parasitic loss efficiency	93% of capacity due to parasitic electrical needs of compression and treatment
Fuel use rate	11,250 Btu/kWh generated (HHV) (before parasitic uses)
Gross capacity factor[*]	Assume 93%
Hot water production	3,800 Btu/kWh (net) * % utilization of hot water potential

Note: Raw cost data are in 2008$'s.

[*] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

CHPT: CHP Turbine-Generator Set	
Typical components include	▸ Gas compression and treatment (includes dehydration equipment, siloxane adsorbers, and filtration); ▸ Heat recovery exchangers; ▸ Turbine and generator (includes exhaust silencers and all wiring and plumbing); ▸ Electrical interconnect equipment; ▸ Site work, housings, utilities, and total facility engineering, design, and permitting; ▸ Gas pipeline from compressor to turbine; ▸ Steam pipelines from turbine to steam user (assumes 2 lines for supply and return); and ▸ Circulation pump for steam pipelines. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost	*For most situations:* [($2,340 * kW capacity) – (0.103 * (kW capacity)^2)] + ($250,000 for interconnect) + ($355 * kW capacity, for heat recovery exchangers) + ($63 * ft of gas pipeline) + ($106 * ft of trench for steam pipelines) + ($12,000 for circulation pump) *For [$2,340 – (0.103 * kW capacity)] < 1,370:* ($1,370 * kW capacity) + ($250,000 for interconnect) + ($355 * kW capacity, for heat exchangers) + ($63 * ft of gas pipeline) + ($106 * ft of trench for steam pipelines) + ($12,000 for circulation pump)
Annual O&M cost (excluding energy)	$0.0144 * kWh generated/yr (before parasitic uses)
Parasitic loss efficiency	88% of capacity due to parasitic electrical needs of compression and treatment
Fuel use rate	13,000 Btu/kWh generated (HHV) (before parasitic uses)
Gross capacity factor[*]	Assume 93%
Steam production	5,500 Btu/kWh (net) * % utilization of steam potential

Note: Raw cost data are in 2008$'s.

[*] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

CHPM: CHP Microturbine-Generator Set	
Typical components include	▸ Gas compression and treatment (includes dehydration equipment, siloxane adsorbers, and filtration); ▸ Heat recovery exchangers; ▸ Microturbine and generator (includes exhaust silencers and all wiring and plumbing); ▸ Electrical interconnect equipment; ▸ Site work, housings, utilities, and total facility engineering, design, and permitting; ▸ Gas pipeline from compressor to microturbine; ▸ Water pipelines from microturbine to hot water user (assumes 2 lines for supply and return); and ▸ Circulation pump for water pipelines. (Includes all equipment downstream of collection and flaring system.)
Installed capital cost	$\left(\$20{,}057 * (\text{kW capacity})^{0.6207}\right) + [\left(\$20{,}057 * (\text{kW capacity})^{0.6207}\right) * (0.06,$ for heat recovery exchangers)] + ($63 * ft of gas pipeline) + ($106 * ft of trench for water pipelines) + ($12,000 for circulation pump)
Annual O&M cost (excluding energy)	$\$0.0773 - 0.00987 * \ln(\text{kW capacity})$
Parasitic loss efficiency	83% of rated capacity due to parasitic electrical needs of boost compressor and cooling water pumps, fans, and dryer system
Fuel use rate	14,000 Btu/kWh generated (HHV) (before parasitic uses)
Gross capacity factor[*]	Assume 93%
Hot water production	5,800 Btu/kWh (net) * % utilization of hot water potential

Note: Raw cost data are in 2008$'s.

[*] Gross capacity factor accounts for loss of energy production due to problems in the gas collection system, problems with project equipment, weather related interruptions of the local utilities, and shut-downs at the energy consumer end of the system.

ECN: Economic Analysis

Economic Inputs:

Rows 4-25   These data are user-specified inputs that are retrieved from the INP-OUT worksheet.

Row 28   Initial IRR estimate used by Microsoft® Excel's IRR calculation function.

Row 29   LFG heat content calculated using user-specified methane heat content.

Inputs Calculated from Other Worksheets:

Rows 33-43   These data are the results calculated on other worksheets and brought to the ECN worksheet for use in the economic analysis.

Economic Analysis (Rows 46 to 92):

Row 46	**<u>Year of operation</u>**	The chronological year in the life of the project. The zero year is the year of construction and year 1 is the first year of operation.
Row 47	**<u>Revenue</u>**	The revenues from selling gas, electricity, CNG, or CHP hot water/steam.
Row 48	<u>Direct-use or High Btu Gas sales</u>	*For Direct-use*: (ft^3 LFG sold)*(Btu/ft^3)*(million Btu/10^6 Btu)*($/million Btu)*(price escalation equation[a]); *For High Btu*: (High Btu gas produced (million Btu)*($/million Btu)*(price escalation equation[a])
Row 49	<u>Electricity sales</u>	(kWh electricity produced)*($/kWh)*(price escalation equation[a])
Row 50	<u>CNG sales</u>	(GGE produced)* ($/GGE)*(price escalation equation[a])
Row 51	<u>CHP hot water/steam sales</u>	(million Btu water/steam produced)*($/million Btu)*(price escalation equation[a])
Row 52	**<u>Operating cost</u>**	The operating and maintenance costs for the project, calculated on the various technology worksheets.
Row 53	<u>Greenhouse gas credit</u>	(avoided CO_2 emissions-$MTCO_2E$)*($/$MTCO_2E$)*($10^6$ $MTCO_2E$/ $MMTCO_2E$)
		This credit can include direct methane emissions as well if indicated in the ***Optional User Inputs*** table of the INP-OUT worksheet.
Row 54	<u>Renewable electricity credit</u>	(kWh electricity sold)*($/kWh)
		Provides credits to LFG electricity projects that utilize tradable renewable energy certificates (TRCs) or "green tags."
Row 55	<u>Renewable fuel credit</u>	(GGE produced)*($/gal)
		Provides credits to CNG projects including projects that use Renewable Identification Numbers (RINs) where a gallon of renewable fuel produced in or imported into the United States receives a credit.
Row 56	<u>Leachate credit</u>	Gallons leachate evaporated)*(avoided $/gallon)*(general escalation equation[a])
		The avoided cost for not treating the leachate when using a leachate evaporator.

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ECN: Economic Analysis

Economic Analysis (continued)

Row 57	<u>Gas royalty</u>	(ft^3 LFG utilized)*(Btu/ft^3)*(million Btu/10^6 Btu)*(royalty $/million Btu)
		A royalty paid to landfill for use of LFG.
Row 59	**Down payment**	Portion of capital cost not financed. (total capital cost)*(% down payment)
Row 60	**Construction grant**	A government cash grant towards project capital costs.
Row 61	**Loan (principle)**	The levelized annual loan payment – calculated using Microsoft® Excel's payment function, based on interest rate, loan period, and amount borrowed.
Row 62	**Loan (interest)**	Annual interest on remaining loan balance (principle). (total capital cost – down payment)*(% interest rate)
Row 63	**Equity payment**	Amount of annual loan payment applied to principle. (annual loan payment) – (annual interest)
Row 64	**Principle remaining**	Unpaid loan principle. (previous year principle) – (previous year equity payment)
Row 65	**Depreciation**	The straight line depreciation of capital cost for tax purposes. (total capital cost) / (project life-years)
Row 67	**Tax liability**	Sum of revenues minus expenses. (direct or high Btu gas sales) + (electricity sales) + (CHP hot water/steam sales) + (greenhouse gas credit) + (renewable electricity credit) + (leachate credit) – (operating cost) – (gas royalty) – (interest) – (depreciation)
Row 68	**Tax before credit**	Estimation of base tax before energy credits. (tax liability)*(marginal tax rate)
Row 69	**Tax credit**	Sum of energy credits. (LFG utilization credit) + (electricity generation credit) + (High Btu production credit)
Row 70	**Net tax**	Sum of taxes minus tax credits. (tax before credit) – (tax credit)
Row 72	**Net income**	Sum of revenues less operating costs. (direct or high Btu gas sales) + (electricity sales) + (CHP hot water/steam sales) + (greenhouse gas credit) + (renewable electricity credit) + (leachate credit) – (operating cost) – (gas royalty) – (interest) – (depreciation) – (net tax)
Row 75	**Cash flow**	Sum of annual cash flows. (net income) – (down payment) + (construction grant) + (depreciation) – (equity payment)
Row 77	**Internal rate of return**	The return on investment based on cash flow. (calculated using Microsoft® Excel's "IRR" function based on cash flow)

ECN: Economic Analysis

Economic Analysis (continued)

Row 79 **Cumulative cash flow**   The sum of cash flows to-date.
                                          (previous year's cumulative cash flow) + (present year cash flow)

Row 81 **Simple payback (years)**   The years of operation required for the cumulative cash flow to become a positive value, based on an evaluation of values in Row 79. This parameter is used only as an error-checking tool.

Row 84 **Present value of cash flow**   Present value (PV) of the year's cash flow based on discount rate.
                                          (cumulative cash flow) / (compounded discount rate)

Row 87 **NPV**   The net present value (NPV) or initial monetary value that is equivalent to the sum of the cash flows, based on the discount rate. This value is determined from the cumulative PV (Row 90) at the end of the project life.

Row 90 **Cumulative present value**   The sum of the PVs of cash flow to-date.
                                          (previous year's cumulative PV) + (present year PV)

Row 92 **NPV payback (years)**   The years of operation that are required for the cumulative PV to become a positive value, based on an evaluation of values in Row 90.

Optimization for Calculating Initial Product Price Needed to Achieve Financial Goals:

Rows 96-151   These data are used to calculate the initial product price required to achieve the financial goals of the project. The equations in rows 105-151 duplicate the structure of Rows 46-92 and are used to test various initial product prices for the purpose of converging on a net present value of $0.

Other Economic Assumptions:

Salvage Value and Decommissioning Cost

For simplicity, LFGcost-Web does not consider the salvage value of the equipment nor the costs to recover the site, at the end of the project life. Due to the nature of LFG energy projects, these costs are mutually off-setting and generally result in a minimal impact to the overall economic evaluation of the typical LFG energy project.

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[a] Escalation equations use a formula of $[1 + ((\% \text{ escalation after year 1})/100)]^{(\text{year of calculation} - 1)}$

Appendix A:
Default Value Documentation

Appendix A: Default Value Documentation

Loan Lifetime

The loan lifetime is assumed to begin during the year of project design and construction. It is common for project loan periods to be limited to half or two-thirds of the equipment lifetime to assure that the loan is repaid before the project ends. Since much of the equipment used in LFG projects has a projected lifetime of 15 years, the default loan lifetime is set to 10 years.

See Table D-1 of Appendix D (Evaluating Local Government-Owned Projects) for recommended default assumptions for municipalities using budgeted funds or public bonds to finance projects.

Interest Rate

Interest rates fluctuate with economic conditions and many unforeseen factors, making them very difficult to forecast. The default interest rate is based on the 5-year average value of the Moody Corporate AAA and BAA bond rates published by the Federal Reserve. The 5-year average rate of 5.6% for 2008-2012 is rounded to 6% for the default rate.

For projects owned by municipalities, the recommended interest rate is based on the 5-year average value of the State & Local Bond Rates published by the Federal Reserve. The 5-year average rate of 4.4% for 2008-2012 is rounded to 5% for the recommended rate shown in Table D-1 of Appendix D (Evaluating Local Government-Owned Projects).

Users can obtain up-to-date interest rates from the Federal Reserve at
http://www.federalreserve.gov/releases/h15/.

General Inflation Rate

The general inflation rate fluctuates with economic conditions and many unforeseen factors, making it very difficult to forecast. The default inflation rate is based on the 5-year average annual increase in the Consumer Price Index (CPI). The 5-year average annual CPI rate increase of 2.1% for 2008-2012 is rounded to 2.5% for the default rate. Users can obtain up-to-date CPI rates from the U.S. Department of Labor at http://www.bls.gov/cpi/.

Equipment Inflation Rate

The *Chemical Engineering* (*CE*) Plant Cost Index was used to determine the default equipment inflation rate. The average annual cost increase for the 5 years of 2008-2012 has been 2.4%. This rate was rounded to 2% for the LFGcost-Web default equipment inflation rate. Users can obtain up-to-date *CE* Plant cost indices from the *Chemical Engineering* magazine published by Chemical Week Publishing, LLC at http://www.che.com.

Marginal Tax Rate, Discount Rate, and Down Payment

The default parameters for corporate tax rate, discount rate, and down-payment of 35%, 8%, and 20%, respectively, are based on recent LFG energy project experience with commercial projects. Corporate discount rates are commonly 2% to 3% higher than interest rates and 7% to 8% higher than inflation rates.

Appendix A: Default Value Documentation (Continued)

Projects owned by municipalities will generally experience different values for these parameters. Municipal tax rates are generally zero percent and municipalities may use a discount rate of zero percent for municipal projects. Municipalities tend to fund a project from municipal revenue,

resulting in a down payment of 100%. See Table D-1 of Appendix D (Evaluating Local Government-Owned Projects) for recommended default assumptions for municipalities using budgeted funds or public bonds to finance projects.

Landfill Gas Production Prices

LMOP reviewed quotes from the U.S. Energy Information Administration (EIA) *Annual Energy Outlook 2014 Early Release* (December 2013), which forecasts a 2014-2015 Henry Hub natural gas price of $3.74 per million Btu. The current natural gas price is depressed as a result of abundant domestic supply and efficient methods of production. Based on Cornerstone's experience with LFG energy contracts, LFG pricing can be based on a contract-defined LFG percent methane value times the Henry Hub natural gas delivery price, with a defined price floor and ceiling. Using the default methane content of LFG of 50%, the rounded value for LFG is estimated to be $1.75 per million Btu. Users can obtain current Annual Energy Outlook prices at http://www.eia.gov/forecasts/aeo/.

Electricity Generation Prices

The *Annual Energy Outlook 2014 Early Release* forecasted electricity generation prices to be 6 cents per kWh in 2015. Recent research indicated LFG electricity prices range from 2.5 to 11 cents per kWh. Since LFGcost-Web has an option for users to specify an alternative price, LMOP recommends a default price of 6 cents per kWh. This default price represents the base electricity price, excluding any incentives.

CHP Hot Water/Steam Production Prices

The average market price for hot water/steam sold by LFG energy CHP projects is estimated to be $4.50 per million Btu. This price is estimated from the $3.74 per million Btu natural gas price divided by a boiler efficiency of 80%. Although natural gas prices have decreased sharply, a default of $4.50 per million Btu for CHP hot water/steam is still an appropriate default value.

High Btu Gas Production Prices

LMOP based the high Btu gas price on the *Annual Energy Outlook 2014 Early Release*. As stated above, the report forecasts a 2014-2015 natural gas price of $3.74 per million Btu. Based on Cornerstone's experience with LFG energy contracts, LFG pricing of high Btu is typically pegged to 70-75% of natural gas prices, giving a rounded value of $2.75 per million Btu for compressed and conditioned LFG.

Appendix A: Default Value Documentation (Continued)

CNG Production Prices

According to the U.S. DOE Alternative Fuels Data Center, the average CNG price between 2008 and 2013 was $2 per gasoline gallon equivalent (GGE). LFGcost-Web uses a default price of $2 per GGE, which represents the base CNG purchase price, excluding any incentives. Users can obtain up-to-date CNG prices from U.S. DOE at http://www.afdc.energy.gov/fuels/prices.html.

Electricity Purchase Prices

The default price paid by landfills for electricity, when they do not produce their own electricity, is assumed to be 8.5 cents per kWh. The 2015 average national electricity price paid by industrial and commercial consumers as forecasted in the *Annual Energy Outlook 2014 Early Release*, is 6.9 and 10.2 cents per kWh, respectively. The average of these two prices is 8.5 cents per kWh.

Annual Product and Electricity Purchase Price Escalation Rates

The average escalation rate for energy products sold by landfills and for energy purchased by landfills was assumed to be 1%. In the *Annual Energy Outlook 2014 Early Release,* EIA expects that commercial natural gas prices will rise by an average rate of 1% and commercial electricity prices will rise by 0.9% in years 2015-2019.

Appendix B:
Common Abbreviations

Appendix B: Common Abbreviations

AP-42	EPA's Compilation of Air Pollutant Emission Factors
Btu	British thermal units
CE	*Chemical Engineering*
CHP	combined heat and power
CNG	compressed natural gas
CO_2	carbon dioxide
CPI	Consumer Price Index
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ft	feet
ft^3	cubic foot / cubic feet
gal	gallon
GHG	greenhouse gas
GWP	global warming potential
HDPE	high density polyethylene
HHV	higher heating value
IRR	internal rate of return
k	methane generation rate constant
kW	kilowatt
kWh	kilowatt-hour
L_o	potential methane generation capacity of waste
lb	pound
LFG	landfill gas
LMOP	Landfill Methane Outreach Program
MHz	megahertz
mi	mile
min	minute
$MTCO_2E$	metric tons of carbon dioxide equivalents
$MMTCO_2E$	million metric tons of carbon dioxide equivalents

Appendix B: Common Abbreviations (Continued)

MSW	municipal solid waste
MT	metric ton
MW	megawatt
NPV	net present value
NSPS/EG	New Source Performance Standards/Emission Guidelines for MSW Landfills
O&M	operation and maintenance
PV	present value
TRCs	tradable renewable certificates
yr	year

Appendix C:
Evaluating Projects with
Multiple Equipment and/or Start Dates

Appendix C: Evaluating Projects with Multiple Equipment and/or Start Dates

LFG energy projects with multiple equipment and/or start dates can also be evaluated using LFGcost-Web. These complex LFG energy projects may include: dual projects (i.e., combining an engine with a direct-use project), staggered projects (e.g., installing an engine early in the life of the landfill and adding additional engines as the gas volume increases), and back-to-back projects (e.g., replacing an engine at the end of its 15-year life with a new engine). The general approach to evaluating these types of complex LFG energy projects is to evaluate each project component individually. If each project component, such as one engine, has a positive NPV then the overall project will also have a positive NPV. The following discussion addresses how to set up the individual component evaluations in LFGcost-Web and how to interpret the results produced by LFGcost-Web.

Required User Inputs − When entering landfill information into the **Required User Inputs** table, enter the standard landfill information that applies to the entire landfill. For the project information inputs (e.g., *LFG energy project type*, Y*ear LFG energy project begins operation*), enter the information that applies only to the specific project component that is being evaluated. For example, staggered and back-to-back project components will each have a different project start year. Model users should generally decline the required input to "include collection and flaring costs" in the evaluation. If users want to include the collection and flaring costs, this option should be selected only for the first project component to be installed. The evaluations of all subsequent components should decline to include the collection and flaring costs.

Optional User Inputs − All inputs in this section should be specific to the project component being evaluated. When entering the *LFG energy project size*, users **must** select the user-defined option, "Defined by user". On the next line, users must enter the *Design flow rate* for the project component being evaluated. The optional input data relating to the landfill itself (e.g., *Average depth of landfill waste* and *Landfill gas collection efficiency*) should apply to the overall landfill, and therefore should remain the same for each project component. All other information entered in this data input section should apply only to the project component being evaluated.

Outputs − After completing the required and optional user inputs, the economic evaluation of the project component appears in the **Outputs** table. The output values *Total lifetime amount of methane collected and destroyed* and *Average annual amount of methane collected and destroyed* apply to the entire landfill. All other output values, such as *GHG value of total lifetime amount of methane utilized in energy project* or *Internal rate of return*, apply only to the project component being evaluated. It is important to note that *Total installed capital cost for year of construction* and *Net present value at year of construction* are presented in terms of the construction year's actual dollars, and *Annual costs for initial year of operation* are presented in terms of actual dollars for the year the LFG energy project begins operation. Therefore, the NPV of multiple project components will be in terms of different years' dollars and cannot be summed to obtain an accurate total project NPV.

Checking the integrity of the complex project component evaluation − After an LFGcost-Web evaluation has been conducted for each project component, a check must be made to ensure that the net capacity for the project components does not exceed the capacity of the landfill. This

Appendix C: Evaluating Projects with Multiple Equipment and/or Start Dates (Continued)

integrity check can be conducted easily using LFGcost-Web's graphical output in the CURVE worksheet. Model users should compile the graphs generated by LFGcost-Web for each component to confirm that the net gas use in any given year does not exceed the gas output of the landfill. Figure C-1 illustrates how graphs from three LFG energy project components can be manually compiled by users to confirm that the components do not exceed the LFG generation capacity. Figures C-1A, C-1B, and C-1C are the curves generated by LFGcost-Web for each individual project component – A, B, and C, respectively – compiled in Figure C-1. In this example, the size of project components B and/or C might be increased by as much as 50 percent and not exceed the gas generation potential of the landfill.
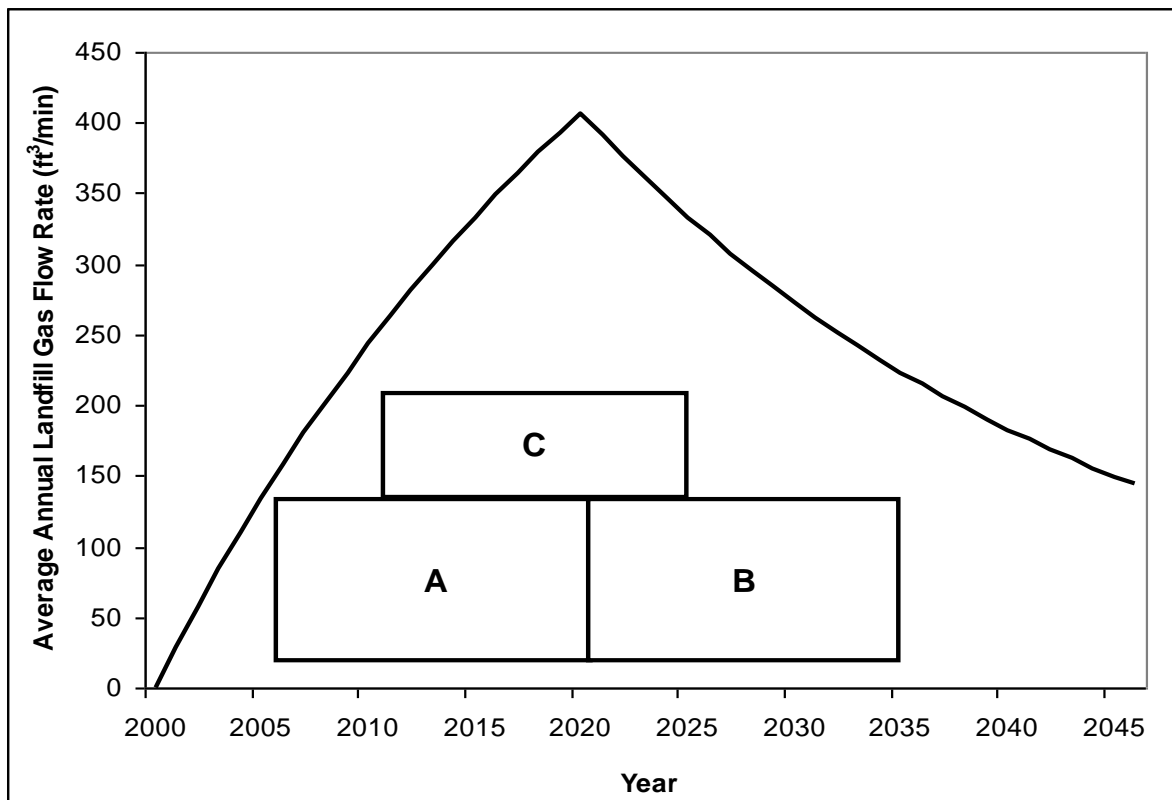

Figure C-1. Example of a project with multiple equipment and start dates

Appendix C: Evaluating Projects with Multiple Equipment and/or Start Dates (Continued)
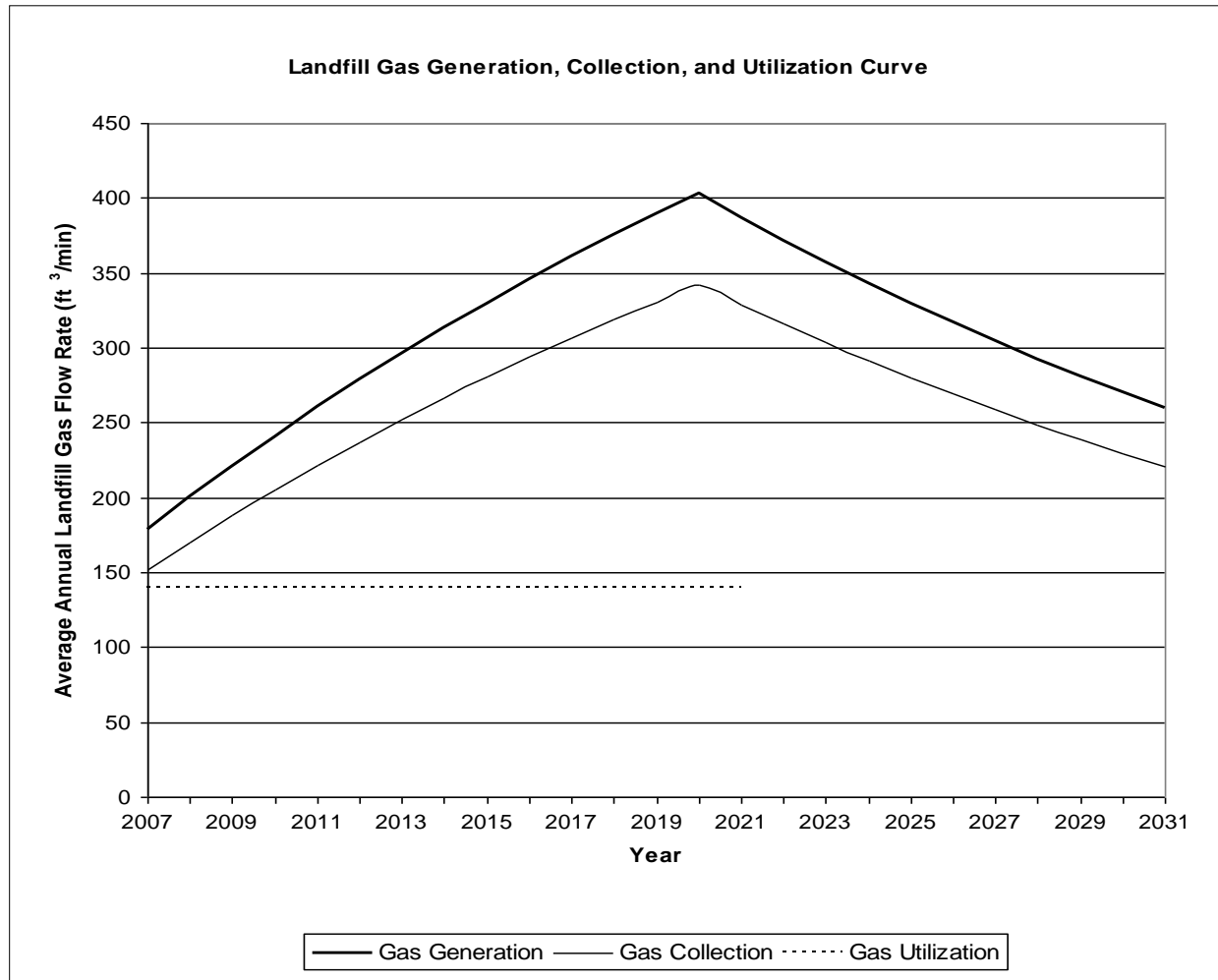

Figure C-1A. Example of an LFG generation, collection, and utilization curve for project component A

Appendix C: Evaluating Projects with Multiple Equipment and/or Start Dates (Continued)
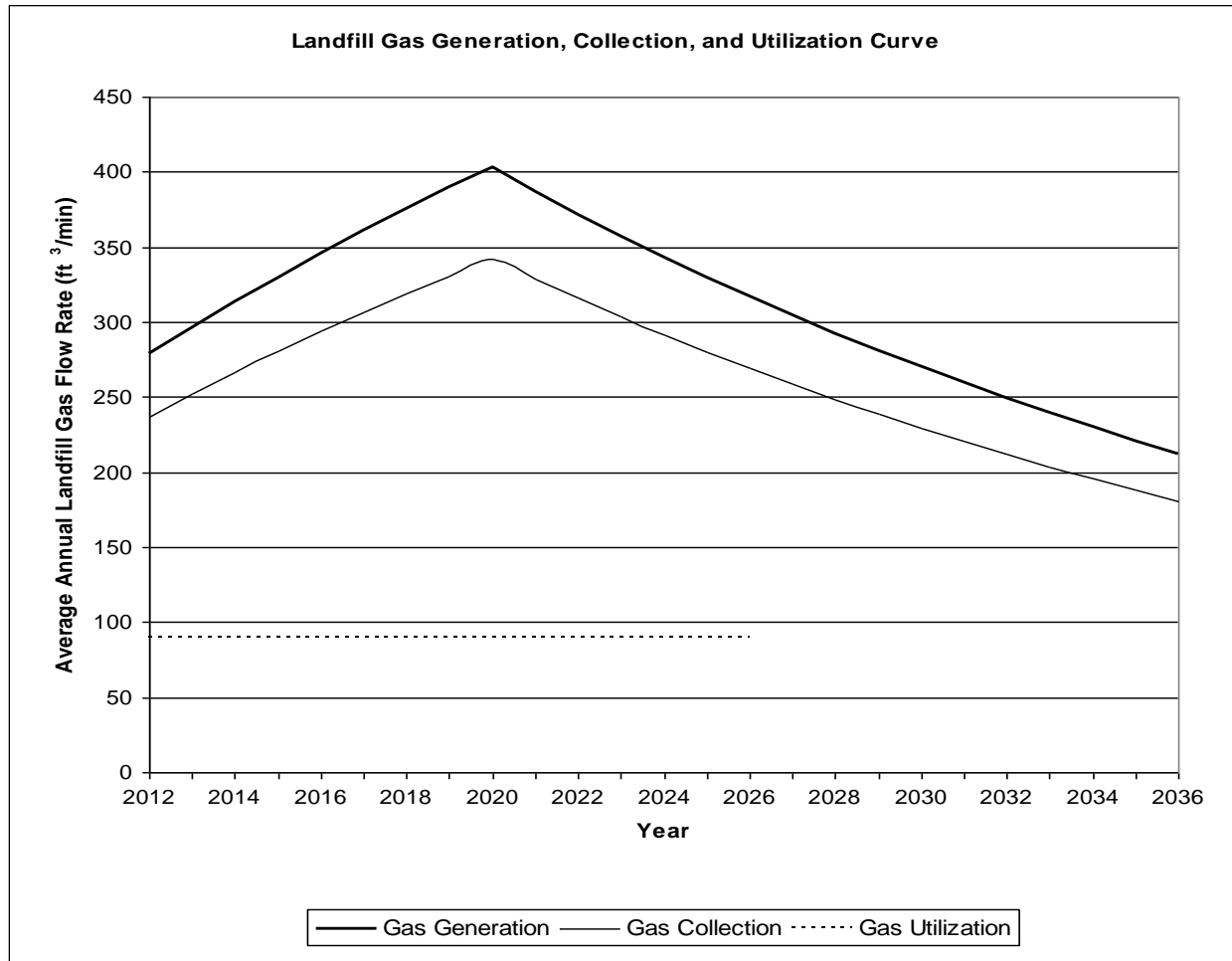

Figure C-1B. Example of an LFG generation, collection, and utilization curve for project component B

Appendix C: Evaluating Projects with Multiple Equipment and/or Start Dates (Continued)
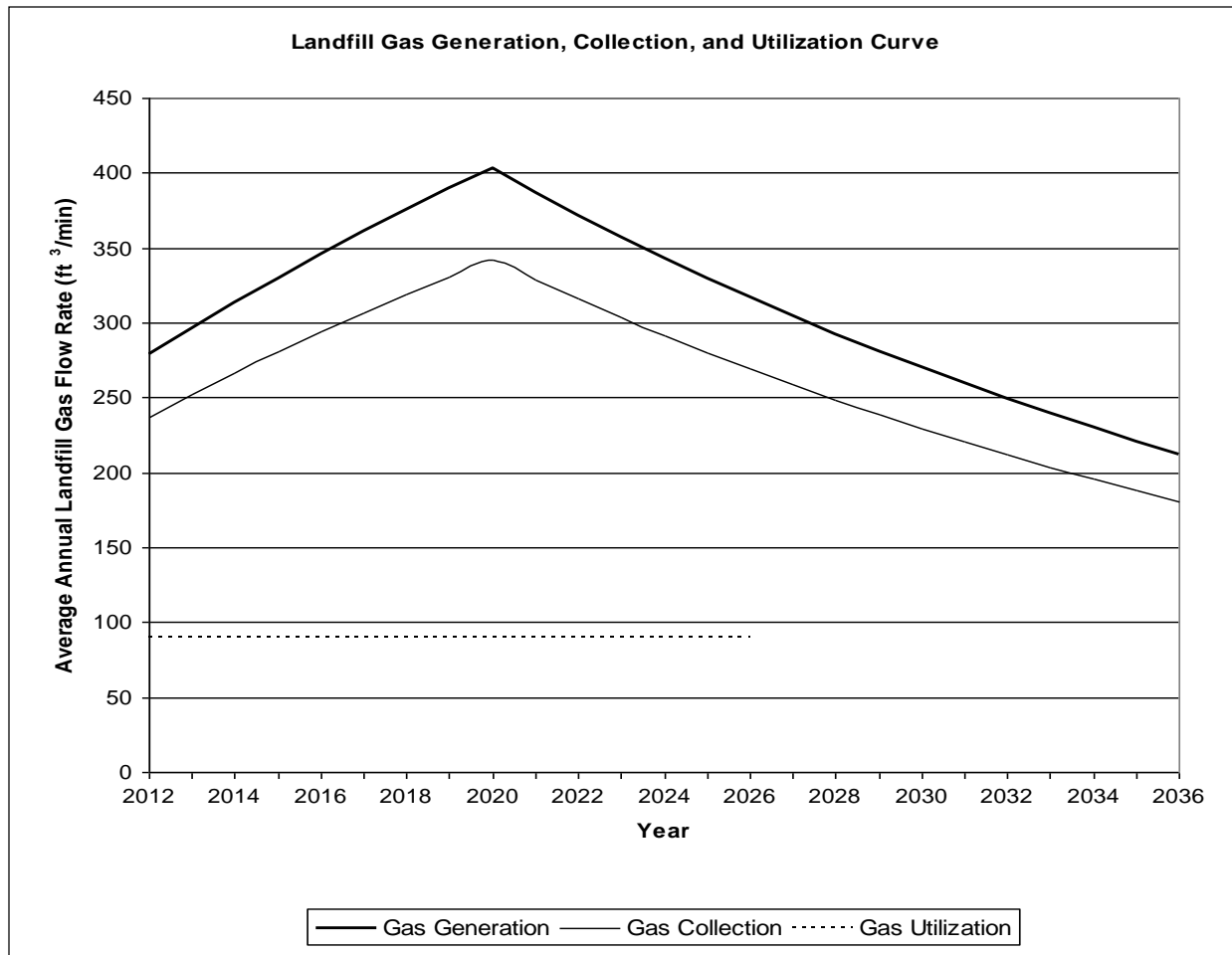

Figure C-1C. Example of an LFG generation, collection, and utilization curve for project component C

Appendix D:

Evaluating Local Government-Owned Projects

Appendix D: Evaluating Local Government-Owned Projects

Projects owned by local governments and other public entities should be evaluated under a different set of economic assumptions than the default values recommended in the LFGcost-Web model. These entities are normally exempt from taxes, are subject to lower discount rates, and use different approaches than private corporations to finance projects. They may finance smaller projects directly from budgeted funds, and choose to fund larger projects through the use of low-interest public bonds. Table D-1 presents default assumptions for use with two types of local government-owned projects.

Table D-1. Recommended Default Assumptions for Local Government-Owned Projects

Parameter	Budget Financed	Bond Financed
Loan lifetime (yrs)	0	10-15 [varies by project lifetime]
Interest rate (%)	0	5
Marginal tax rate (%)	0	0
Discount rate (%)	5	5
Down payment (%)	100	0

Appendix E:

Evaluating Boiler Retrofit Projects

Appendix E: Evaluating Boiler Retrofit Projects

For boiler retrofit projects, there is a required input for users to indicate whether the boiler retrofit costs will be standalone (i.e., evaluated from the perspective of the end user) or combined with direct-use project costs (i.e., evaluated from the perspective of a developer that is responsible for all costs). The outputs of the economic analysis will vary depending on which perspective is used to evaluate the boiler retrofit costs. Specifically, IRR, NPV, and NPV payback will vary based on the appropriate prices (in $/million Btu) entered for the LFG product price and royalty payment in the *Optional User Inputs* table. The following discussion addresses how to set up boiler retrofit scenarios in LFGcost-Web and how to interpret the results produced by LFGcost-Web.

Boiler retrofit costs kept separate from direct-use project costs – For evaluating the cost of only the boiler retrofit from the perspective of the end user, the following optional inputs are used:

- ▸ *Initial year product price: Landfill gas production* ($/million Btu) should be set to the price that the end user is currently paying for natural gas.

- ▸ *Royalty payment for landfill gas utilization* ($/million Btu) should be set to the price that the end user will pay the pipeline owner for delivery of LFG to the end user's property boundary.

- ▸ Economic parameters such as *Loan lifetime*, *Interest rate*, *Discount rate*, *Marginal tax rate*, and *Down payment* should be the parameters used by the end user.

The difference between the royalty payment and the LFG production price is the revenue used to justify the cost of the boiler retrofit. All economic outputs for this scenario such as IRR, NPV, and payback are for the end user paying for the boiler retrofit, not the developer of the overall project.

Boiler retrofit costs combined with direct-use project costs – For evaluating projects from the perspective of a developer that will pay for LFG treatment (skid-mounted filter, compressor and dehydration unit), pipeline delivery from the landfill to the end user's boiler, and conversion of the boiler, the following optional inputs are used:

- ▸ *Initial year product price: Landfill gas production* ($/million Btu) should be set to the price that the developer will sell LFG to the end user.

- ▸ *Royalty payment for landfill gas utilization* ($/million Btu) should be set to the price that the developer will pay the landfill owner for raw LFG.

- ▸ Economic parameters such as *Loan lifetime*, *Interest rate*, *Discount rate*, *Marginal tax rate*, and *Down payment* should be the parameters applying to the developer.

The difference between the royalty payment and the LFG production price is the revenue used to justify the cost of LFG treatment, the pipeline, and the boiler retrofit. All economic outputs for this scenario such as IRR, NPV, and payback are for the developer paying for the overall project.